EngD Thesis Report

Lifetime extension assessment of collected washing machines

By: Frank Stiksma
Date: August 30, 2023
Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS), University of Twente

EngD thesis

Lifetime extension assessment of collected washing machines

To obtain the degree of
Engineering Doctorate (EngD) at the University of Twente,
on the authority of the Rector Magnificus
Prof.Dr.Ir. A. Veldkamp
on account of the decision of the graduation committee,
to be defended
on Thursday 7th September 2023 at 1.30 p.m.

by

Frank Kornelis Sytze Stiksma
Born on the 21st of August 1971
In Vollenhove, the Netherlands

EngD candidate

Author	Frank Kornelis Sytze Stiksma

Supervision

The EngD thesis is approved by:

Daily and thesis supervisor: Dr. M.J. van Sinderen.
Co-supervisor: dr. L.O. Bonino da Silva Santos MSc
Company supervisor: M.I. Mann MSc

Organization

University	University of Twente
Faculty	Faculty of Electrical Engineering, Mathematics and Computer Science University of Twente
Commissioning company	CirkelWaarde

Graduation committee

The graduation committee consists of:

Director EngD programme	Dr. L. Ferreira Pires
Supervisor	Dr. M.J. van Sinderen
Daily supervisor	Dr. L.O. Bonino da Silva Santos
External examiner	Dr. A. Martinetti
External examiner	Dr. M.W.J. Flooren
Supervisor commissioning company	M.I. Mann MSc

Abstract

In recent decades, the amount of electronic waste has increased rapidly. Under the influence of the principles of a linear economy, most discarded consumer electronics devices are treated as if they no longer have any residual value. As a result, materials recycling of consumer electronics is the most preferred circular strategy. However, the transition to a circular economy requires that the application of lifetime extension strategies should maximize the residual value of collected electronics. This study exclusively focuses on the washing machine product category. Collection agents play a critical role in identifying and utilizing the residual value of collected consumer electronic products. In practice, it is a complicated task for collection agents to objectify the residual value of collected washing machines to make informed decisions about the feasibility of lifetime extension. Indeed, the opportunistic behavior of washing machine ecosystem stakeholders and the limited access to product and usage data for collection agents hamper the ambition to extend the lifetime of washing machines on a large scale.

In this EngD study, socio-technical scenarios have been developed that provide insight into the critical forces that determine the extent to which data are accessible to collection agents in order for them to fulfill their circular role. Based on the design science research methodology, a vision for a lifetime extension information system has been developed for a projected 2030 scenario that supports collection agents in assessing whether extending the lifespan of collected washing machines is feasible. This assumes full-data availability and accessibility. The information system consists of a registration component, a database management system, a decision support system, and a business intelligence visualization component. Future product life cycle data of washing machines in digital product passports support the lifetime extension assessment. The assessment component has been concretized as part of the decision support system in the study for a 2030 scenario. To this end, a data structure of the passport has been developed that contains decision-supporting data. A process diagram provides insight into how a data-driven lifetime extension assessment of collected washing machines can lead to an informed decision about lifetime extension.

The study revealed that the lifetime extension assessment of washing machines should be approached from a systemic, holistic perspective and cannot be exclusively assigned to collection agents. Consequently, lifetime extension is a collaborative task for the entire washing machine ecosystem. Cooperation and information sharing between stakeholders in the washing machine ecosystem are therefore necessary to maximize the residual value of collected washing machines.

A detailed practical assessment component supports collection agents in the current context to objectively determine whether lifetime extension is feasible. Influenced by the absence of product and usage data, derived data properties have been defined for the assessment component. The assessment component was extensively tested on collection agents during validation studies with experts and a layperson. These validation studies clarified that lifetime extension assessment is affected by the harvesting of parts and the existence of repair facilities.

The contribution of this design research enables collection agents to have a practical assessment instrument that supports them in their lifetime extension assessments of collected washing machines. The detailed data-driven information system and the conceptualization of a digital product passport for washing machines provide collection agents with guidance on how to take up their future circular role. This study contributes to the scientific literature on lifetime extension assessment methods and the related conceptualization of digital product passports for the product category washing machines. Future research should focus on circular ecosystem configurations that stimulate product lifetime extension, the large-scale demonstration and testing of the current assessment component, the detailing of the information system for collection agents, which will allow interoperability and compatibility with external data sources and systems to utilize the possibilities that digital passports offer, and the formulation of the appropriate data governance rules.

Keywords: E-waste, product lifetime extension, circular ecosystem, decision support system, washing machines.

Table of contents

List of abbreviations

BI	Business Intelligence
DBMS	Database Management System
DPP	Digital Product Passport
DSS	Decision Support System
EEE	Electric and Electronic Equipment
E-product	Electric and Electronic product
EPREL	European Product Registry for Energy Labelling
EU	European Union
GDPR	General Data Protection Regulation
SPSS	Statistical Package for the Social Sciences
WEEE	Waste of Electrical and Electronic Equipment
WEEELABEX	Waste Electric and Electronic Equipment LABel of EXcellence

List of figures

List of tables

1 Introduction

This chapter introduces the research context, problem statement, and methodological approach underlying this EngD thesis. **Section 1.1** explains the research context by discussing the transition to a circular economy, the increase in electronic waste, the need for product lifetime extension of electrical and electronic equipment, and the challenge of collection agents –here represented by CirkelWaarde-- to facilitate this ambition on a larger scale. **Section 1.2** elaborates on the problem statement. **Section 1.3** discusses the project goals of this study and related system artifacts and research questions. **Section 1.4** presents the methodological approach that underlies this study. Finally, **Section 1.5** explains the structure of the EngD thesis.

1.1 Problem context and background

1.1.1 Transition to circular economy

Increased scarcity of raw materials, environmental issues, and geopolitical dynamics put pressure on the security of the supply of raw materials and the economy. As a response, the Dutch government is striving for a fully circular economy by 2050 (Ministerie Infrastructuur & Milieu, 2016). The national government aims to halve consumption of raw materials in 2030 (PBL Plan Bureau Leefomgeving, 2019).

A circular economy is the means to realizing a sustainable future (Neves & Marques, 2022). According to the Ellen MacArthur Foundation (2016), “A circular economy is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times.” Elimination of waste and pollution, circulation of products and materials at their highest value, and the regeneration of nature are central to this. The circular economy responds to the current linear ‘take-make-dispose’ model (Bocken et al., 2016; Geissdoerfer et al., 2017) (see **Figure 1-1**). In such a linear system, raw materials are sourced, transformed into products, sold to consumers, and used by them until finally discarded as waste without exploring the possibilities of reuse (Daou et al., 2020; Ghisellini et al., 2018). The leading assumption is that there are infinite resources (Patwa et al., 2021). Selling as many products as possible is the main driving force in such a linear economic system, but causes negative externalities, such as biodiversity loss, waste, pollution, energy inefficiencies, and resource losses (MacArthur, 2013).

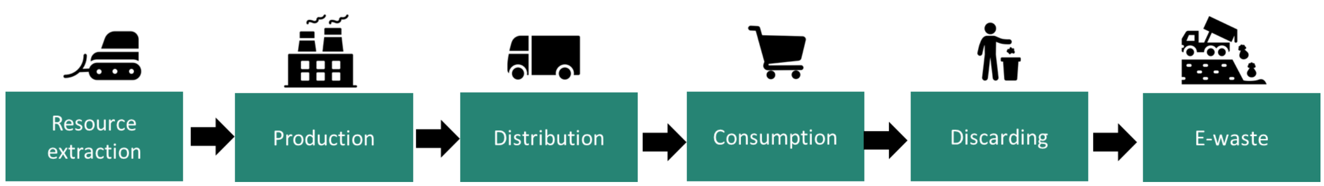


Figure 1-1: Take-make-discard model in a linear economy

The negative consequences of the currently predominant ‘take-make-dispose model’ requires a far-reaching systemic transition to a circular economy system “in which resource input and waste, emission, and energy leakages are minimized by cycling, extending, intensifying, and dematerializing material and energy loops. This can be achieved through digitalization, servitization, sharing solutions, long-lasting product design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling" (Geissdoerfer et al., 2020, p. 5). Circular economy requires a systemic perspective at multiple scale levels (Kirchherr et al., 2017). Value is created at the micro level (products, businesses, consumers), mesa level (eco-industrial parks), and macro level (city, region, nation, and beyond), to achieve sustainable development while simultaneously improving environmental quality, economic prosperity, and social justice, for the benefit of present and future generations.

The transition to a circular economy has been slow in the take-up in the Netherlands (PBL, 2021). Dutch raw material consumption is still high, and national targets for waste still need to be achieved. The recent Circularity Gap Report 2023 reveals that overall only 7.2% of all material inputs into the global economy consists of secondary materials (De Wit, 2022). Consequently, global dependencies on virgin materials sources are still significant. Scientific research on the circular economy reveals that empirical analysis of the topic is limited and more advice is needed for companies to be able to implement the concept of circularity in business practices (Kirchherr & van Santen, 2019). The transition to a circular economy is complex and slowed down by different types of barriers (Bressanelli et al., 2019; Ghisellini & Ulgiati, 2020; Grafström & Aasma, 2021; Kirchherr et al., 2018; Neves & Marques, 2022; van Langen et al., 2021), such as:

- Technological barriers, such as a lack of circular product design, ineffective waste management infrastructure, lack of IT systems to monitor circular economy initiatives, limited data-driven and digital tools to scale circularity, lack of waste stream data, and limited information sharing among value chain partners;
- Market barriers, such as ill-functioning resale markets, low price virgin materials, price volatility of recycled materials, and cannibalization;
- Institutional barriers, such as a lack of circular economy policies and poor implementation, obstructive waste legislation, and unclearly defined circular economy metrics;
- Socio-cultural barriers, such as consumerist culture, predominance of the linear system, a lack of willingness to collaborate in the supply chain, and careless behavior in product usage.

As policy maker, regulator and facilitator, governments play a vital role in starting the transition to a circular economy (Köseoğlu, 2022). At the end of 2022, the Dutch government introduced an updated circular economy policy. The government prioritizes the electrical appliances product group because of its significant impact on people and the environment (Ministry of I&W, 2022). Compared to other prioritized consumer goods (such as furniture, textiles, packaging, and consumables) consumer electronics have the most significant adverse climate, environmental and health impact throughout their lifecycle (see **Table 1-1**).

Consumer goods categories	Spendings of households	Climate impact	Biodiversity impact	Environmental impact	Health impact
Chemical products	17,36%	12,43%	-	15,77%	15,96%
Electrical equipment	17,21%	47,58%	1,61%	44,82%	37,42%
Furniture	13,38%	6,03%	8,90%	5,12%	6,83%
Textile	42,98%	24,50%	31,08%	20,69%	23,70%
Packaging & consumables	9,07%	9,45%	13,90%	13,59%	16,09%
Grand total	100,00%	100,00%	100,00%	100,00%	100,00%

Table 1-1: Environmental impact analysis consumer goods, 2015 (source: (Ministerie Infrastructuur & Waterstaat, 2022, p. 58)

Despite the negative environmental impact of electrical and electronic equipment, the transition to a circular economy is problematic within the electrical and electronic equipment sector (Guzzo et al., 2021; Rizos & Bryhn, 2022). To accelerate the circular transition, the national government has tightened up its circularity goals for 2030:

- 50% of current electrical appliances should get a longer lifetime through lifetime extension and professionalization and strengthening of the repair, refurbishment, and reuse market, where this is desirable from an environmental perspective;
- In line with the updated EU Ecodesign Directive, all new electrical equipment should be based on circular design principles and energy efficiency;
- 100% of all electrical appliances on the Dutch market should have formalized collection at certified Waste Electrical and Electronic Equipment (WEEE) management collection agents;
- If lifetime extension of electrical appliances is not possible, all electrical equipment should be high-quality recycled.

These circularity goals closely align with the EU's Circular Economy Action Plan (European Commission, 2019). The EU focuses on promoting sustainable consumption, designing sustainable products, improving the collection and treatment of electrical and electronic equipment (EEE), and extending the lifetime of electronic products.

1.1.2 E-waste

Rapidly growing volumes and a high generation rate of discarded electronic and electrical equipment (EEE) causes significant negative ecological impacts. EEE refers to "equipment which is dependent on electronic currents or electromagnetic fields in order to work" (Al-Salem et al., 2022, p. 3), or "Any household or business item with circuitry or electrical components with power or battery supply" (Step Initiative, 2014, p. 4). EEE consists of six categories: temperature exchange equipment (refrigerators, freezers, air conditioners), screens and monitors (television, laptops), lamps, large equipment (washing machines, dishwashers, dryers), small equipment (e.g., vacuum cleaners, microwaves, shavers, and electronic tools), and small IT and telecommunication equipment (mobile phones, GPS systems, printers) (Forti et al., 2020). Within the European Union, 55% of discarded EEE consists of large equipment, such as washing machines.

EEE becomes E-waste once its owner has discarded it as waste without the intention of reusing it (Step Initiative, 2014). According to the Global E-waste Monitor, the amount of E-waste worldwide in 2019 was 53.6 million metric tons (Forti et al., 2020). Annually, E-waste will grow by approximately 2 million metric tons globally to 74 million metric tons in 2030. The causes of the rapid growing E-waste stream can be traced back to multiple factors, such as economic prosperity, decreased product lifetime, malfunctioning, obsolescence, design strategies, repairability, technological innovation, sales-oriented business models, changing consumer needs, new product features and poor E-waste collection (Bocken et al., 2016; Jaiswal et al., 2015; Johnson et al., 2018; Kumar et al., 2017; Sabbaghi et al., 2017). In 2019, each resident of the Netherlands generated an average of 21.9 kilograms of E-waste (Forti et al., 2020). A significant proportion of E-waste processing takes place through unofficial channels, resulting in leakage flows to parties that are not WEEELABEX certified (Waste Electric and Electronic Equipment LABel of Excellence) in the Netherlands and abroad (Kumar et al., 2017). If E-waste is not adequately processed, the toxic chemicals in the discarded EEE can cause severe health and environmental problems (Islam & Huda, 2018; Rautela et al., 2021). At the same time, E-waste has economic value because it contains precious metals (Kumar et al., 2017). Moreover, product lifetime extension strategies, such as Reuse, Repair, and Refurbishment, can be part of the value proposition, value creation and delivery, and value capture logic in circular business models (Bocken & Ritala, 2021; Ertz et al., 2019; Rizos & Bryhn, 2022).

1.1.3 Product lifetime extension

Circularity can be realized by slowing (design of long-life goods and product-lifetime extension), narrowing (reduced resource use), and closing resource loops (recycled goods or materials used in a new product life cycle) (Bocken et al., 2016; Geissdorfer et al., 2017; Stahel, 2016). The concept of a circular economy relates closely to the waste hierarchy (Pires & Martinho, 2019): the circular strategies, the so-called '4Rs' Reduce, Reuse, Recycle, and Recovery, are prioritized in a desired order (Alcalde-Calonge et al., 2022; Kirchherr et al., 2017). Waste prevention strategies such as Reduce are at the top of the waste hierarchy, and disposal is at the bottom. The preventive Reduce circular strategy aims to prevent waste by buying fewer items, using fewer materials, keeping the product for longer, and applying circular design principles (Pires & Martinho, 2019). Sub-strategies such as Refuse, Rethink and Redesign are part of this Reduce strategy. The other R strategies involve waste. The Reuse strategy and sub-strategies, such as Repair, Refurbish and Remanufacture, aim to extend a product's lifetime and its parts (Potting et al., 2017). The collection of used products and high-level Reuse strategies contribute to the realization of this ambition (Patwa et al., 2021). Recycle and Recover strategies, on the other hand, aim at a useful application of materials. Each R strategy is relevant depending on the phase in a product's life cycle.

Extending the lifetime of EEE, covered by the Reuse strategy and the sub-strategies Repair and Refurbishment, is a crucial enabler in accelerating the transition to a circular economy. As part of a 'slowing loop strategy', product lifetime extension aims to prolong the useful life of products (Ertz et al., 2019). Optimizing lifetime by designing long-life products and encouraging the reuse of products, parts, and materials ensures that the economic and ecological values of electronic products are preserved for as long as possible and prevents unnecessary value destruction. Product lifetime is "the useful life of a product; the time during which the product remains integer and usable for its primary function for which it was conceived and produced" (Ertz et al., 2019, p. 867). Thus, product integrity relates to the extent to which a product remains identical to the original 'factory fresh' configuration (Bakker et al., 2014). In a circular economy it is desirable to keep a product in its original condition for as long as possible. However, currently, short-lived products and early obsolescence negatively affect the product lifetime of EEE products. The aesthetic, social, technological, economic, logistic, functional, planned, or psychological obsolescence of a product results in increasing E-waste volumes (Mellal, 2020). However, product obsolescence does not necessarily have to be permanent but can be replaced by product lifetime extension strategies (Ertz et al., 2019). Hence, a product potentially has multiple use cycles during its entire life. Product lifetime extension can be realized by applying abovementioned 4R strategies, such as Reuse, Repair or Corrective maintenance, and Refurbishment (Fontana et al., 2021; Pan et al., 2022). **Table 1-2** presents the definitions of each R strategy.

Circular strategies	Definitions
Reuse and resell	"Reuse and resell can be defined as the second or further use by another consumer of a discarded product that is still in good condition and does not require any correction or repair action. The resold or reused products retain their function and identity."
Repair or Corrective Maintenance	"Set of activities performed on a defective product so it can be used with its original function. Repair is also making a broken product operational again through fixing/replacing failed parts. The objective of repair is "bringing back to working order", "making it as good as new", "recreating its original function after minor defects", "replacing broken parts."
Refurbishment	"Refurbish means restoring an old product and bringing it up to date. In general, refurbished products are upgraded and brought back to specified quality standards or satisfactory working and/or cosmetic conditions and have to fulfill extensive testing. Occasionally, refurbishing is combined with technology upgrading by replacing outdated modules and parts with technologically superior ones."

Table 1-2: Definitions of circular strategies (Fontana et al., 2021, p. 13)

1.1.4 CirkelWaarde

In this EngD study, CirkelWaarde acts as client. CirkelWaarde is a raw materials alliance of waste management companies AVU, ROVA, and Circulus. In line with the principles of a circular economy, the CirkelWaarde partners do not position themselves as waste collectors but as second-life raw materials suppliers. As a contribution to a systemic transition to a circular economy, CirkelWaarde strives to use the residual value of collected products and waste materials in a sustainable and responsible manner. From their joint expertise center, in 2020 an 'E-novation Hub' in the Cleantech Region was launched. In this hub Saxion University of Applied Sciences, municipalities, waste management companies, recycling companies, recyclers, and collection agents investigate how discarded EEE can be collected, reused, repaired, or refurbished based on circular economy principles. The aim is to extend the life of at least 10% of collected EEE. The E-novation Hub's focus is on research into systematized collection of discarded EEE as well as safe testing, repair, and possibly certification of discarded EEE with a focus on product repair, recovery of parts, and overhaul. The CirkelWaarde Expertise Center collects and shares the knowledge and methodologies with interested parties, such as governments, collectors, E-waste chain parties, recycling companies, knowledge institutions, companies, and industry associations. The CirkelWaarde partners indicate that, as collectors of discarded EEE, instruments and practical instruments to systematically and objectively assess possible lifetime extension of discarded products are required. Participatory observations as part of this EngD study at multiple collection locations revealed that currently the collection agents are mainly focused on the reception and sorting of discarded EEE in product categories. Assessment for possible lifetime extension is secondary. A quick check for possible lifetime extension is mainly based on subjective grounds and often depends on employees' motivation and attitude. The CirkelWaarde partners stated that due to the lack of decision-support instruments and information in the E-waste value chain, collected consumer electronics are rarely reused to maximum effect, and the link to promising regional sales markets is minimal. Operational protocols and assessment instruments to help employees at collection points to systematize the process of receipt, intake, and determining circular reuse options are currently lacking.

1.2 Problem statement

Discarded EEE is collected at municipal collection points, collecting thrift stores, EEE repairers, retailers, third-party recycling services, and manufacturers. Collection methods used to collect and sort discarded EEE differ per type of collection point (Islam & Huda, 2018). Collection agents have limited insight into the quantitative performance of the collection of E-waste and the selected circular strategies (Börner & Hegger, 2018). Consumers are insufficiently aware of the economic, ecological, and social value that E-waste represents and its adverse effects on the environment. Employees at collection points have little technical knowledge and information to support an appropriate circular strategy and treat it accordingly (Govindan & Bouzon, 2018). During its lifecycle, product value diminishes during transport, intake, and storage damage (Johnson et al., 2020). Reverse logistics and collection of EEE products are complicated due to a wide variety of actors generating E-Waste, diversity in logistics collection channels, varying product quality and lifetime expectancy of consumer electronics, a multitude of consumer electronics product categories, fluctuating volumes over time and various methods by which the residual value of the discarded consumer electronics is determined (Govindan & Soleimani, 2017; Islam & Huda, 2018).

A critical factor that complicates lifetime extension is that the current E-waste system has been designed to treat discarded EEE as "end-of-life" products. A product is end-of-life if it has lost its structural performance at the end of its product life cycle, is obsolete, and is discarded (Mellal, 2020). However, in many cases, it is questionable whether a discarded electronic product is functionally and technically obsolete (Ylä-Mella et al., 2022). On the contrary, products are "end-of-use" if they still function, but users no longer use the products for their actual purpose after a useful life. These products are discarded by a user even though they are technically and functionally suitable for extending their lifetime. Consequently, potential remaining economic, technical, ecological, and social value has been destroyed if the "end-of-use" for one user is not followed by a new usage life with another user.

Based on waste hierarchy principles, **Figure 1-2** depicts a circular vision of the CirkelWaarde partners on the value creation and preservation of electronic products. In the production phase, value is added to an electronic product. A product's value is maximum if it is delivered to a customer. Value-adding circular strategies, such as Reuse, Repair, and Refurbishment, retain value longer and enable multiple usage cycles. If these circular strategies are not feasible, harvesting parts and materials may be other appropriate circular strategies. When a product reaches its end-of-life, it becomes E-waste and ideally functions as an input resource in a new production loop (Geisendorf & Pietrulla, 2018). However, in current E-waste management practices, utilization of the end-of-use value of collected consumer electronics is limited. Residual value is often lost during the collection and evaluation process of discarded consumer electronics because, in most cases, discarded EEE products are recycled. Discarders and collectors mostly do not recognize the value of used EEE and treat it accordingly. Collection agents lack the knowledge and experience to decide what is an adequate circular strategy for an electronic product.

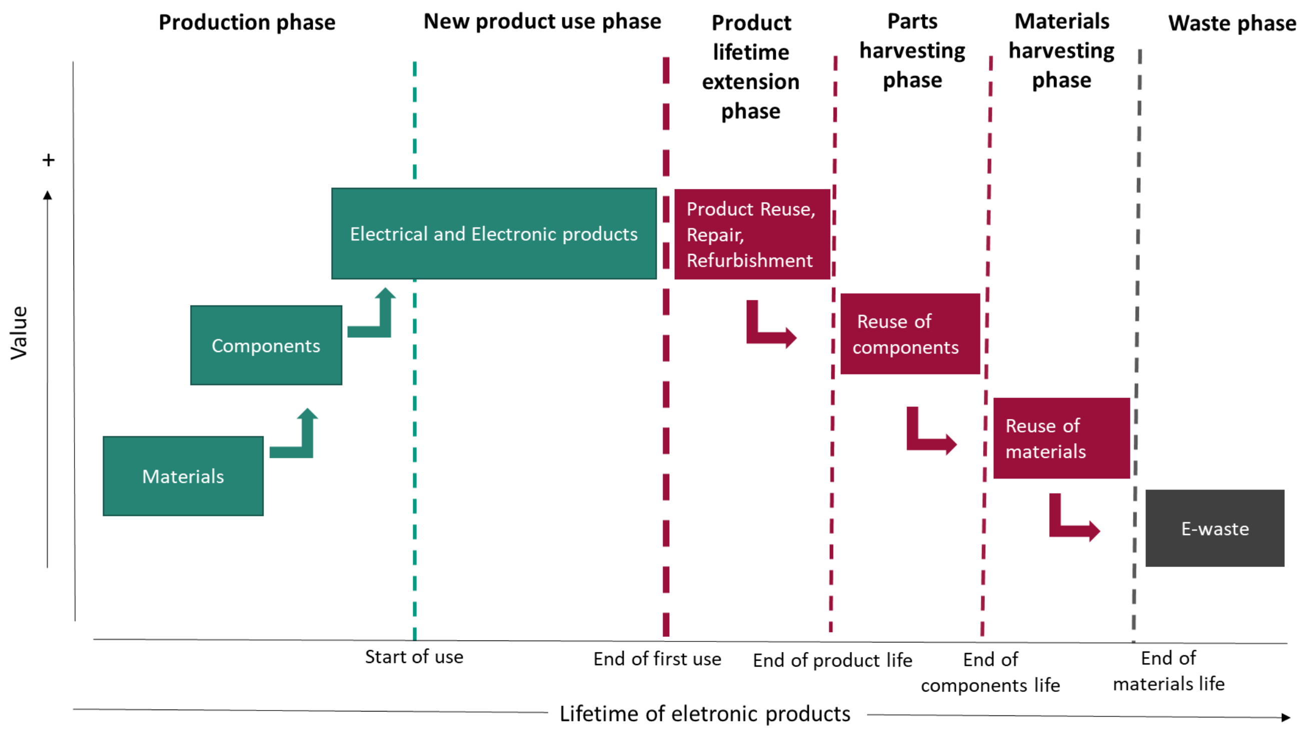


Figure 1-2: Value creation and preservation of electronic products

Another observation is that currently the connection to promising markets for products and available repair strategies is insufficiently made at WEEE collection points. As a result, promising business opportunities are insufficiently exploited, despite the fact that second-hand consumption has grown in recent years (Persson & Hinton, 2023). The business opportunities that product lifetime extension of EEE products can provide, e.g., through reselling of second-hand products, are interesting for entrepreneurs. Circular business models contribute to extended product lifetimes and create, deliver and capture value for users by applying circular strategies, such as Repair and Re-use (Geissdoerfer et al., 2020; Nussholz, 2018). The utilization of as much value as possible from discarded EEE products in a circular value chain can potentially be an integral part of circular business models on promising sales markets for second-hand products. However, the prevailing paradigm among discarders, collection agents, and processors is often that used consumer electronics have little or no value in the existing linear value chain and are treated as such. Realization of the circularity goals requires efforts to arrive at an overarching process approach after the use phase that is aimed at high-quality disposal, intake, and assessment of EEE products. Return evaluation is critical in a circular economy to identify and utilize the embedded values in EEE products (Islam & Huda, 2018). Collection agents, from their waste management expertise, have the potential to take up their role as an assessment center to recognize, explore and acknowledge the embedded value in discarded EEE. Thus, in the transition to a circular economy, collection agents are an essential link in the EEE value chain in identifying embedded values in EEE products, such as economic, ecologic, technical, and social values. These multiple values affect the lifetime extension possibilities of discarded electronic products (see **Figure 1-3**)

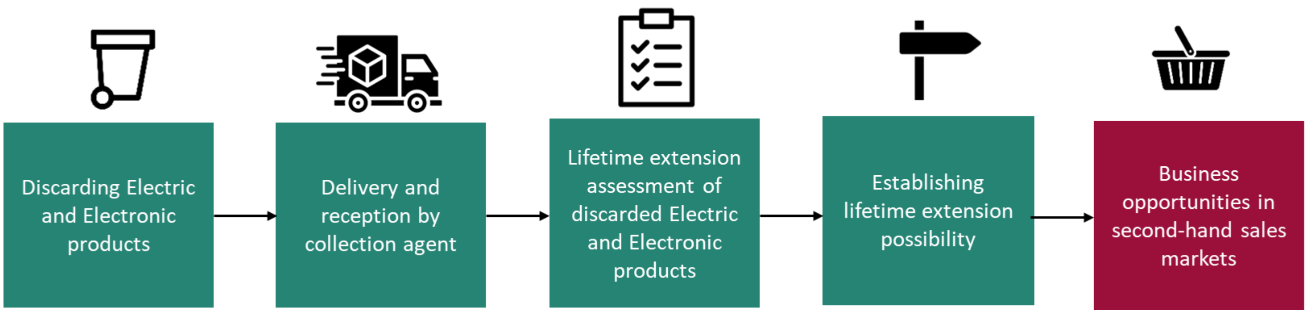


Figure 1-3: Lifetime extension assessment of discarded electronic products in a circular economy

To fulfill their envisioned role as assessment center properly and to facilitate the connection to second-hand sales markets, it is essential that collection agents can objectively explore, recognize and acknowledge the multiple embedded value of collected EEE (Safdar et al., 2020). Before potential business opportunities of second-hand EEE products can be utilized, the assessment of collected EEE products is a critical condition. However, currently, lifetime extension assessment of discarded EEE is limited (Anandh et al., 2021). The lack of extending the lifetime of collected household appliances on a large scale and a system vision on lifetime extension assessment jeopardize the circular objective of having a fully circular economy in 2050 in The Netherlands. Empirical observations of collection agents highlighted that the lack of decision-supporting EEE product and usage information and the absence of structured assessment methods impede informed decision-making about possible lifetime extension.

According to the statistical database Statista, 92% of Dutch households owned a washing machine in 2021. These large numbers of washing machines sooner or later result in a significant E-waste flow causing significant negative environmental impacts (Forti et al., 2020). Therefore, this study focuses on washing machines.

The problem statement of this study is the following:
The lack of decision-support information and a structured lifetime extension assessment method for discarded washing machines complicates informed decisions concerning possible lifetime extension.

1.3 Project goals, system artifacts and research questions

From a business perspective, this study aims to contribute to exploiting the business opportunities collected washing machines offer. Such business opportunities can only be exploited if a reliable, substantiated assessment has been performed by a collection agent to determine the probability of technical lifetime extension. Otherwise, the lack of a critical assessment of lifetime extension would burden sellers with unsuitable washing machines they cannot market. Therefore, a critical condition in this respect is that a probability assessment of extending the lifetime must be made when collecting discarded consumer electronics. The objective of this study is to improve the utilization of the residual value of collected washing machines. Value utilization highly depends on whether lifetime extension of washing machines is economically and technically feasible. This study unravels the guiding principles concerning the lifetime extension assessment of washing machines and the business ecosystem of collection agents that affect the feasibility of lifetime extension. The main project goal of this study is to design an information system for collection agents that supports them in assessing collected washing machines for possible lifetime extension.

The lifetime extension assessment component is a critical part of the information system for collection agents. Digitization enables a circular economy to optimize product life cycles and improve data access and sharing among value chain actors (Antikainen et al., 2018; Hedberg & Šipka, 2021). As part of the European Green Deal, digital product passports (DPP) will become the norm as a circular instrument in this context. These passports contain the desired product life cycle data (Berger et al., 2022; Walden et al., 2021). DPPs can provide a powerful answer to the current lack of product and usage information for washing machines. As part of a future collection information system, the information and data in DPPs could facilitate an objective lifetime extension assessment and enable informed decision-making on collected washing machines. In line with the circularity goals of the Dutch government, which aim to halve raw material consumption by 2030, the application of the DPP is foreseen for this year. In this study, the assumption is made that under the influence of the Circular Economy and Data Act Governance policies and regulations of higher authorities, full data availability will be possible in 2030.

This study distinguishes the following subgoals:

1. Develop a vision that explores how the washing machine ecosystem in which collection agents operate will evolve in the future.
2. Design a generic information system architecture for collection agents that supports the lifetime extension assessment process of collected washing machines.
3. Develop a lifetime extension assessment component that is a partial implementation of the proposed lifetime extension process of collection agents, such that it can be used in current situations and has the potential to evolve for use in future situations. As part of the lifetime extension assessment component, design the data structure and content of a DPP for washing machines.

Figure 1-4 clarifies which system artifacts are developed in this study. Research questions are linked to each system artifact. The first and second system artifacts elaborate on analyzing the current washing machine ecosystem and identifying factors that affect lifetime extension assessment. Based on socio-technical scenarios and a value model, a third system artifact outlines a vision of a future washing machine ecosystem of collection agents. The socio-technical scenario explores how external macro developments and technological innovations influence the socio-technical regime in which collection agents operate. A modelled value network provides insight into the value exchanges between stakeholders to embed lifetime extension as a circular value proposition integrally in a circular ecosystem. The fourth system artifact is a generic vision of an information system architecture for collection agents that supports lifetime extension assessment of washing machines. In an envisioned 2030 scenario, the fifth system artifact concerns the specification of the information system architecture in a lifetime extension assessment component and a data-driven assessment process that facilitates collection agents. The information and data in the DPP support the lifetime extension assessment process of collection agents. The sixth system artifact concerns the design of a lifetime extension assessment component and process for the current situation. Concrete implementation in the current assessment process of collection agents in the short term is leading here.

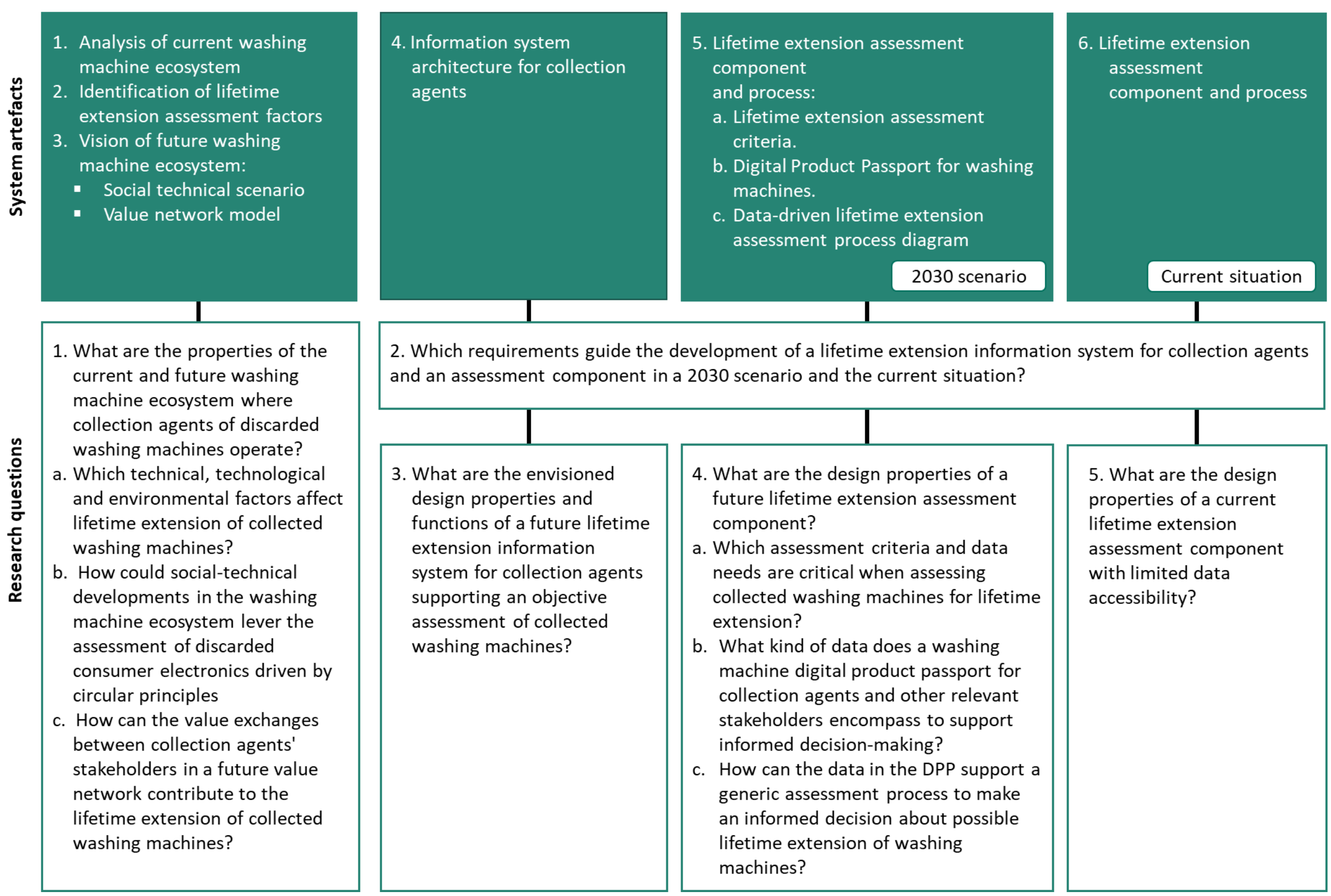


Figure 1-4: System artifacts and research questions

1.4 Research design and methodology

During this study system's research and design process, principles of the design science methodology were followed. Design science refers to designing and investigating artifacts in their context (Wieringa, 2014). These artifacts interact with a problem context aiming to improve something in this context. The Design Science Research Cycles are a valuable overarching design methodology framework at a meta-level to guide and justify this study's cyclic-iterative research and design process activities. The design science methodology is extensively used in Information Systems and Software Engineering (Wieringa, 2014). Design science research is centered around three research cycles: the Relevance, Rigor, and Design cycle (Hevner, 2007; Hevner et al., 2004). In the Relevance cycle, the purpose, the problem, the scope of an artifact, the requirements, and the practical and scientific relevance are addressed. Field testing tests whether the artifact is usable and meets the intended objective. Thus, the Relevance cycle links the contextual environment to the design science activities. In the Rigor cycle, scientific theories, domain expertise, and methods are introduced into the design research project contributing to the innovation of design artifacts. Conversely, the knowledge generated by the developed design makes a valuable contribution to the scientific knowledge base, domain experience, and expertise. In the design cycle, design artifacts and processes are constructed and evaluated. The Design cycle is fed by the gains from the Relevance and Rigor cycle. The three cycles are run through several times in a cyclic-iterative process. The model by Hevner (2007) shows that sound design science research not only aims at its practical utility but also that the synergy between the three cycles in a balanced design of design artifacts is vital.

Wieringa's (2014) framework for design science in **Figure 1-5** elaborates on Hevner's (2007) three-cycle view of design science research. This framework has been leading during this study's design and research activities. **Figure 1-5** clarifies the relevance of the social and knowledge context in the research and design process leading to the design of the defined artifacts and the other way around. The research and design process incorporates problem investigation, treatment design, and treatment validation.

The design science methodology and the design research methods applied during the system development process are specified in the following chapters.

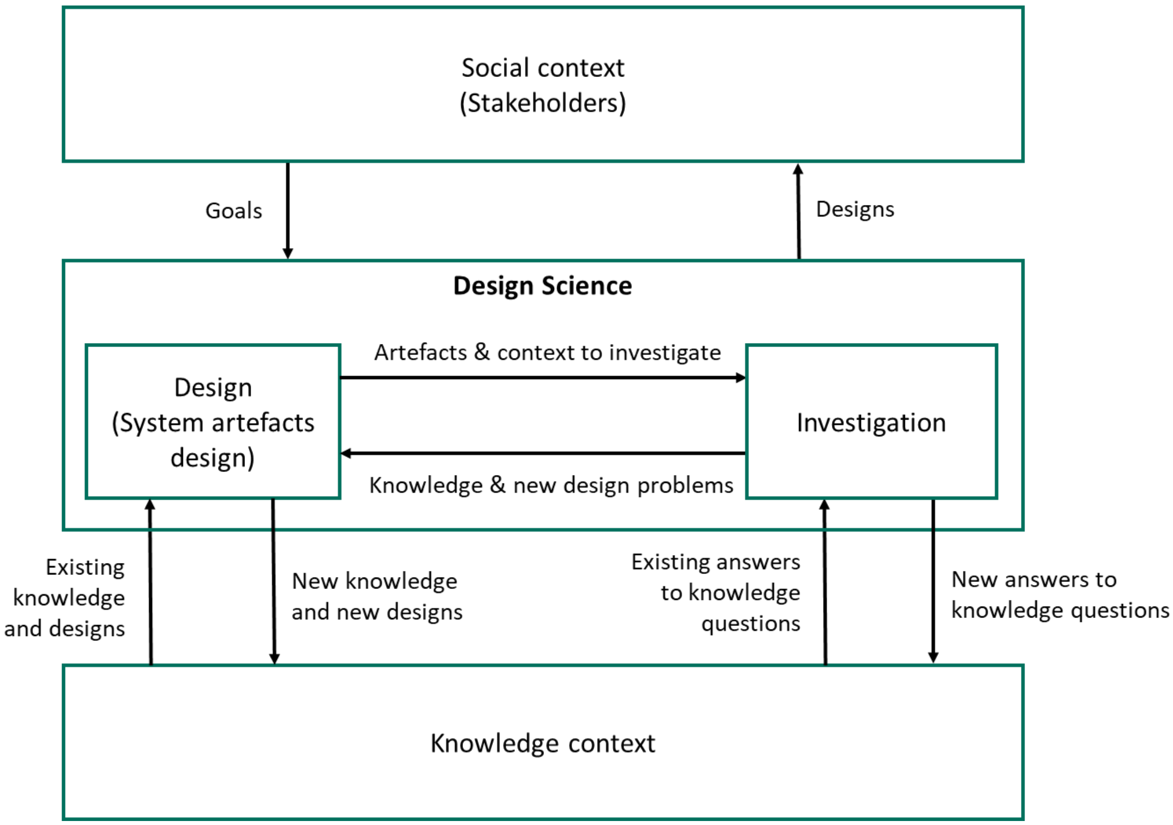


Figure 1-5: Design Science framework (source: Wieringa, 2014, p.7)

1.5 Outline of report

This EngD thesis is structured as follows (see **Figure 1-6**). **Chapter 2** details the problem investigation. **Chapter 3** presents a vision of a future washing machine ecosystem. **Chapter 4** present the requirements elicitation. **Chapter 5** entails the elaboration on a lifetime extension information system for collection agents. **Chapter 6** details the data structure of a DPP for washing machines and its application in a lifetime extension assessment component and process in a 2030 scenario. **Chapter 7** presents the design of a lifetime extension assessment component and process for the current situation. **Chapter 8** concludes the EngD thesis by discussing the main findings, contributions, limitations, and future work.

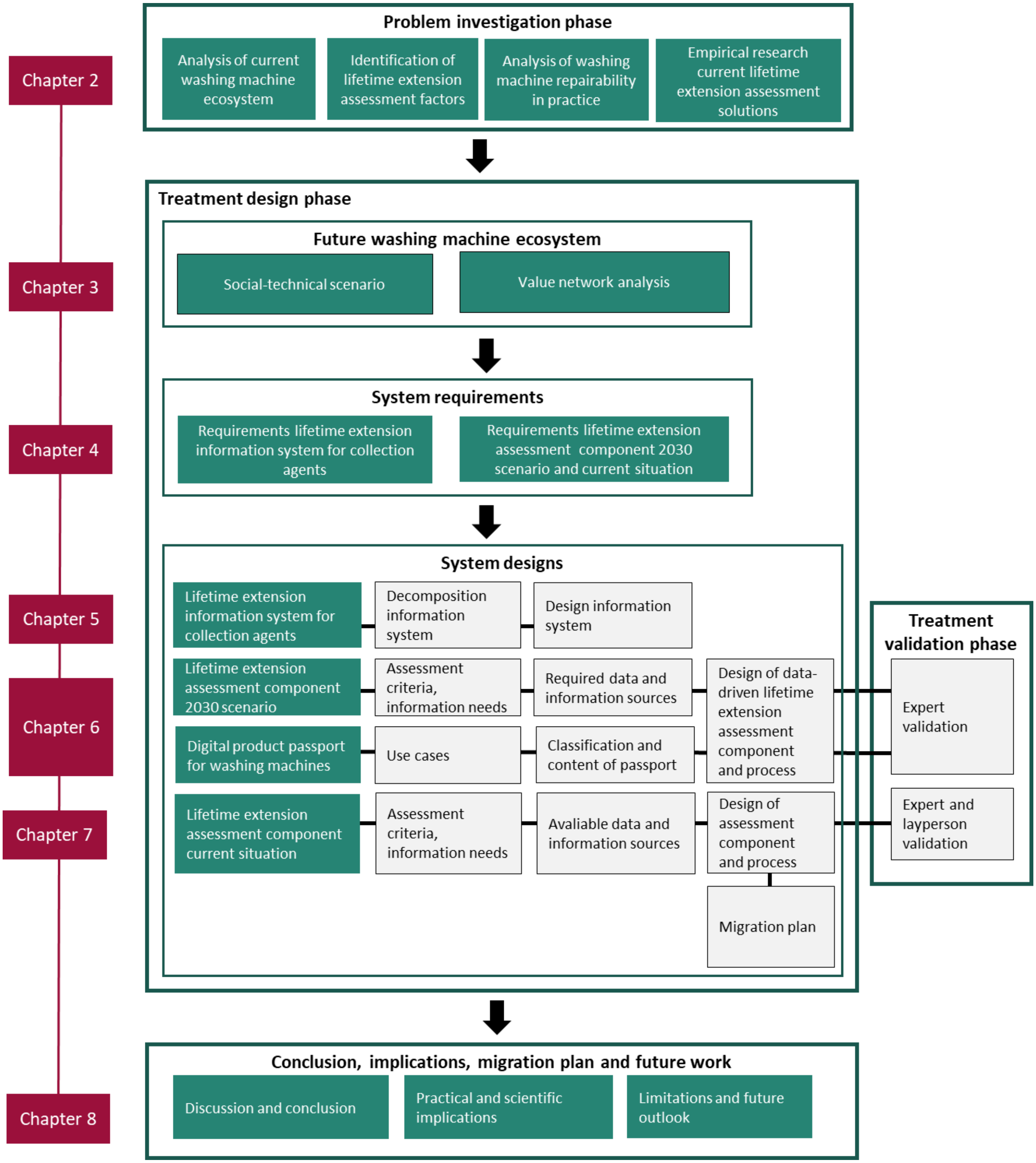


Figure 1-6: Structure EngD report

2 Problem investigation

This chapter explores the problem investigation from several perspectives. **Section 2.1** presents an analysis of the current washing machine ecosystem in which collection agents operate. **Section 2.2** outlines the literature review results concerning relevant lifetime extension assessment factors and relevant digital developments. **Section 2.3** presents the results of interviews with repairers about the repairability of washing machines. **Section 2.4** explores current system solutions at different organizations concerning assessing returned goods for lifetime extension. **Section 2.5** recapitulates the relevance of the research findings in the previous sections for the future design of the design artifacts.

2.1 Washing machine ecosystem analysis: current situation

2.1.1 Research design

As part of this analysis, scientific literature on WEEE management was studied. In Google Scholar, based on the keywords “WEEE,” “WEEE industry, “WEEE management,” “E-Waste management,” “Producer responsibility,” and “Waste management,” 17 scientific articles have been selected that provided insight into the collection and processing of E-Waste. In addition to the literature review, semi-structured observations occurred at collection agents where discarded consumer electronics are received, sorted, and processed. The purpose of these observations was to gain insight into the business processes and services of collection agents. Observations were performed at the following collection agents:

1. A collecting thrift store in the center of the Netherlands that receives discarded consumer electronics from citizens on behalf of the municipal waste collector. The collection agents’ activities focus on receiving, sorting, registering, and selecting electronic devices eligible for lifetime extension. In a technical workshop, the technical statuses of selected devices are assessed, and any repairs are carried out. The selling of second-hand EEE takes place in a thrift store at the same location. Electronic devices not eligible for lifetime extension are shipped to a WEEELABEX-certified collection agent.

2. A WEEELABEX-certified collection agent in the center of the Netherlands who collects and recycles discarded EEE based on their Extended Producer Responsibility. On a small scale, this collection agent explores the possibilities for reusing devices and parts. The collected EEE comes from retailers, companies, collecting recycling companies.

3. A WEEELABEX-certified collection agent in the South of the Netherlands who collects, distributes and selects discarded washing machines from retailers and companies. Washing machines qualified for lifetime extension are inspected, overhauled, and repaired in a technical workshop at the same location. Refurbished washing machines are sold on Business-to-Business (B2B) markets.

4. A collection agent in the middle and northern part of The Netherlands that focuses on sorting and processing collected E-waste at a material level. Collected washing machines and other consumer electronics are dismantled at this location. Materials that can be recycled are separated and transported to specialized processors.

These collection agents' work processes and process activities were mapped out by flow chart mapping during fieldwork activities and performed observations. Semi-structured interviews were held with the operational managers of each collection agent. These interviews provided insight into the core business activities, the inbound and outbound logistics operations, and the collection and processing activities at the collection agent's location. Based on the collected research results from academic WEEE management literature, field observations, and interviews, the current washing machine ecosystem has been analyzed. During a work session, conceptual analyses of the washing machine ecosystem were presented to three CirkelWaarde partners. Based on their feedback, the ecosystem analyses were refined and finalized.

2.1.2 Stakeholders of the washing machine ecosystem

Several stakeholders can be identified in the washing machines ecosystem. According to Freeman (1994, p. 6), "A stakeholder in an organization is (by definition) any group or individual who can affect or is affected by the achievement of the organization's objectives." Savage et al. (1991, p. 61) define stakeholders as entities that "have an interest in the actions of an organization and the ability to influence it". Stakeholder support is essential for satisfying an organization's minimal needs, creating and sustaining successful coalitions, and ensuring the organization's long-term viability (Bryson, 2003). A stakeholder analysis is advantageous in the identification of the interests of stakeholders, the potential risks facing stakeholders, and any stakeholders who could negatively affect an organization. The conceptual framework of Savage et al. (1991) contributes to a thorough understanding and classification of stakeholders in terms of their relative threat potential and relative cooperative potential. The classification distinguishes four types of stakeholders: non-supportive, marginal, mixed, and supportive. Stakeholder definitions such as those given by Freeman (2010) and Savage et al. (1991) focus on a single organization: in this case, a collection agent providing a collection service. The collection service consists of an invoicing service, an E-waste administration service, a distribution service, and an assessment service (see **Section 2.1.4**).

Table 2-1 provides an overview of the most prominent external stakeholders in a washing machine ecosystem. Their roles, interests, and position in Savage's conceptual framework have been identified. The potential for threat and collaboration in **Table 2-1** is scored for each stakeholder, considering whether their interests incorporate product lifetime extension of washing machines.

Stakeholder	Role	Interest	Potential for threat to collector	Potential for collaboration with collector	Stakeholder typology	Explanation
1. Manufacturers	Producer of washing machines	- Operational efficiency in production - Product innovation - Selling washing machines	High	Low	Non-supportive	- Operating in a supply-oriented linear system - Limited interest in product lifetime extension - Delegates the collection of discarded washing machines to Stichting Open - Product design mostly limits lifetime of washing machines - No focus on reuse of parts and products. - Limited provision of product and usage information to collection agents
2. Retailers	Sales of washing machines	- Selling washing machines	High	Low	Non-supportive	- Sales oriented business models focusing on selling as many new washing machines as possible
3. Users	Purchaser and user of washing machines Disposer of end-of-use and end-of-life washing machines	- Low purchase costs - Well-functioning washing machine - Ease of disposal	High	Low	Non-supportive	- Purchase and usage behavior strongly determine whether product lifetime extension is possible - Poor discarding behaviors
4. Collection agents	Reverse logistics and collection of discarded washing machines	- High collection volumes of discarded washing machines - High product integrity - Financial incentives for materials recycling	Low	High	Supportive	- Favorable collaboration among collection agents in the E-waste value chain
5. Repair facilities	Product recovery of end-of-use washing machines	- Lifetime extension of washing machines	Low	High	Supportive	- Benefit from supply of high-quality discarded washing machines
6. WEEE management centers	Collection, sorting and disassembly of discarded washing machines	- High collection volumes of discarded washing machines - Compliance	High	High	Mixed	- Focus on materials recycling - Affected by interests of manufacturers - First initiatives to extend lifetime of discarded items.
7. Recycling processors	Disassembly and materials recycling	- High collection volumes of discarded washing machines	High	Low	Non-supportive	- Focus on materials recycling
8. Governments	Circular economy policy development, enforcement of waste regulations	- Realization of circular economy	Low	High	Supportive	- Transition to circular economy is increasingly a priority of governements

Table 2-1: Stakeholders in current washing machine ecosystem

In Savage's (1991, p. 65) diagnostic framework, a collection agent's external stakeholders are displayed (see **Figure 2-1**). The diagnoses show that collectors deal with non-supportive stakeholders, such as manufacturers, retailers, users, and recycling processors, who attach limited value to product lifetime extension or collected washing machines. According to (Savage et al., 1991), non-supportive stakeholders are the most problematic. The potential for threat and collaboration of the non-supportive stakeholders is affected by the persistent linear economy paradigm, driven by sales-oriented business models and consumerism. The diagram also clarifies that collectors, repair facilities, and governments benefit from possible lifetime extension initiatives in their cooperation. The positioning of WEEE management centers, that take care of producer responsibility, as a mixed blessing stakeholder is affected by the manufacturers' interest. Overall, collectors deal with many external stakeholders. External stakeholders control critical resources (such as information and financial capital). External stakeholders' power (such as their insistence on not actively participating in the circular collection of discarded washing machines and the dominance of their sales-driven business models) and the lacking of sincere partnerships with collection agents hamper lifetime extension initiatives. These restrictions can be traced back to barriers to implementing circular economy principles in the EEE sector. Such critical barriers are limited collaboration in the E-waste supply chain, industry-organized collection schemes designed to recycle disposed EEE, a lack of legislation setting financial incentives for reuse, limited consumer engagement, organizational inertia, high investment costs for circular processes, a lack of holistic perspective and insufficient ecodesign circularity requirements (Aminoff & Sundqvist-Andberg, 2021; Bressanelli, Saccani, Pigosso, et al., 2020; Rizos & Bryhn, 2022; Zacho et al., 2018).

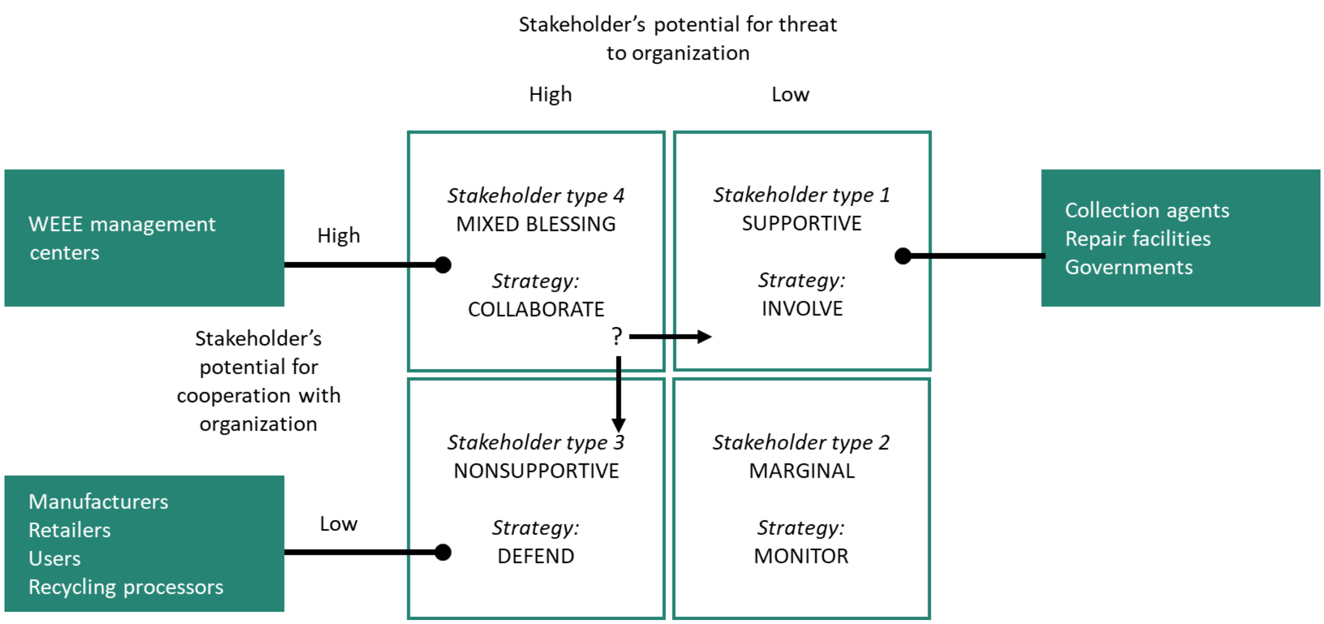


Figure 2-1: Diagnostic typology of current collection agents' stakeholders (Savage et al., 1991, p. 65)

As depicted in **Figure 2-1** and according to Savage et al. (1991), collaboration and involvement of the mixed blessing and supportive stakeholders are appropriate coping strategies. For the identified non-supportive stakeholders, it is best to apply a defense strategy to reduce dependencies. For example, obtaining product information from other sources and participating in circular economy initiatives that strengthen the position of collectors favoring lifetime extension. However, a general strategy should focus on strengthening relationships with ‘non-supportive’ stakeholders by transforming them into ‘supportive’ stakeholders, for example through regulations and financial incentives. Governments could encourage non-supportive stakeholders to participate more actively in the circular initiatives of collection agents.

2.1.3 Forward and reverse supply chain of washing machines

Figure 2-2 depicts a generic process diagram of a forward and reverse flow of washing machines. The forward supply chain relates to the flow of goods from a point-of-origin to a point-of-consumption to satisfy customer requirements (Mboli et al., 2022). Manufacturers, importers, wholesalers, and retailers operate in the forward washing machine supply chain. Manufacturers produce washing machines; importers and retailers realize the connection to sales markets; customers buy a washing machine, use it and discard it when it has reached the “end-of-use” or “end-of-life” stage. Collection agents, WEEE management centers, recycling processors, and E-waste incineration and landfill organizations are part of the reverse washing machine supply chain. According to Mboli et al. (2022), the reverse supply chain focuses on the flow of goods from the point-of-consumption back through the supply chain aiming to recapture value or proper disposal. This EngD study primarily focuses on collection agents in the reverse supply chain of washing machines. However, the envisioned lifetime extension information system depends on the data of forward supply chain stakeholders. Therefore, forward supply chain stakeholders are relevant to incorporate in the analyses in this chapter.

As part of the washing machine supply chain, users largely determine the length of the product life cycle of a washing machine for its intended purpose as well as its structural performance boundaries, such as its functional and technical obsolescence (Ylä-Mella et al., 2022). After the user has discarded the washing machine, it arrives at a collection agent who receives the product. This collection agent can be a municipal, recycling, or commercial collector. Some of these collected washing machines, recognized as “end-of-use,” are sent to repair facilities and fixed, sold to retailers and finally end up with another user for a new usage phase. However, in the current situation, most discarded washing machines arrive at WEEE management recyclers via collection agents or retailers. Manufacturers of electronics and electrical equipment are responsible for returning any equipment they put on the market. Since 2021, Stichting Open has been responsible for the collection & processing of discarded consumer electronics at WEEE management recycling centers, and the reporting thereof, on behalf of the producers. This collection method is in line with the European Union’s WEEE directive, which regulates the collection and recycling of discarded consumer electronics to protect and save the (living) environment (Stichting Open, 2022).

Stichting Open pays collectors a fee per quantity of electronics collected by weight. For the collection of discarded electronics, the national government has set a legal target for collection and processing of at least 65% of the volume of all EEE sold. However, so far, this target percentage has not been achieved. In 2018 50% of E-waste was compliantly recycled, 25% was non-compliantly recycled, and 25% was out of the reach of formal collection and processing channels (Forti et al., 2020). Thus, a significant portion of the E-waste stream in the Netherlands escapes formal collection and processing facilities, such as municipal collection points, retailers and other take-back channels. Under the influence of the 65% standard, the WEEE collection and recycling facilities focus almost entirely on sorting and disassembling electronic products with hardly any consideration for lifetime extension. Subsequently, recycling processors extract materials from discarded electronics. The remaining E-waste is incinerated and ends up in landfills in the Netherlands or abroad.

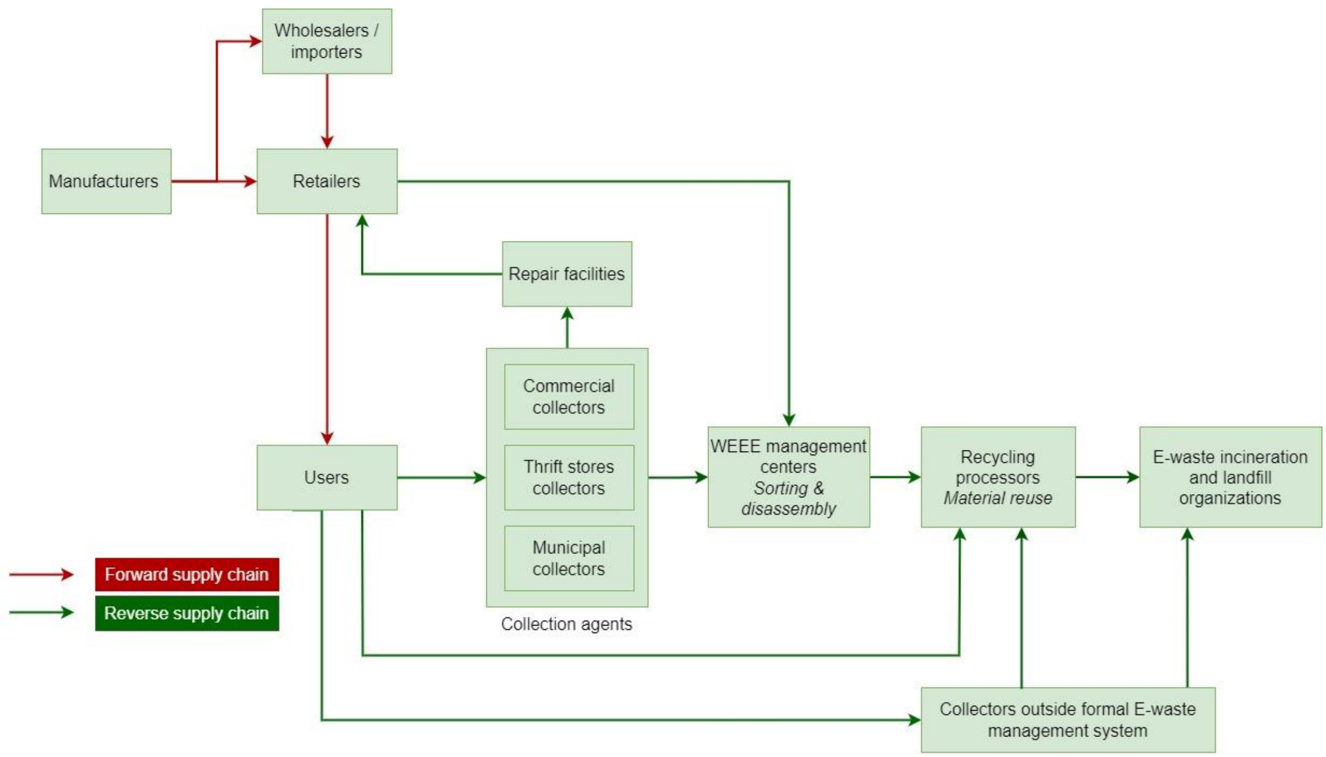


Figure 2-2: Forward and reverse supply chain of washing machines

2.1.4 Stakeholders' drivers in the current washing machine ecosystem

This section identifies the drivers of the different stakeholders involved in the washing machine ecosystem and the collection of washing machines. For this purpose, the Goal Realization Viewpoint in the Archimate language for business architecture was used to model the washing machine ecosystem stakeholders, their goals, and requirements. The assumption is that the elements of Archimate's application layer also apply to stakeholders operating outside a single collection agent's organization. ArchiMate's goal concept represents a high-level statement of intent, direction, or desired end state (Josey, 2018). The requirements of stakeholders in the washing machine ecosystem direct their business goals. Requirements represent the system's desired properties for realizing stakeholders' goals. In the case of a collection agent organization, instances of the goal concept are used to model how stakeholders' motivations influence and constrain a current collection service provided by a collection agent. **Section 2.1.5** explains the content of the collection services that collection agents deliver.

Figure 2-3 provides insight into the essential process steps in collecting, assessing lifetime extension, and distributing collected washing machines. The execution of these three process steps leads to the realization of a collection service for customers by a collection agent. Stakeholders have an interest in the collection service to realize their goals and to set their requirements accordingly. The objectives of the stakeholders influence the formulated requirements for the collection service. In addition to the previously identified washing machine ecosystem stakeholders (see **Table 2-1**), stakeholders have been added who are interested in the lifetime extension of collected washing machines, namely society and three stakeholders promoting repair.

In **Figure 2-3** the collection process is linked to the stakeholders involved, their requirements, and their goals. These stakeholders are directly or indirectly interested in a well-functioning collection service provided by a collection agent. However, not all stakeholders are direct users or customers of a collection agent's collection service. For example, a producer delegates its legal collection responsibility to a WEEE management collector, and a repair information provider can operate separately from a collection agent.

Society can be considered as a relevant stakeholder because the needs of present and future generations have to be met. This means that a collection service should place a minimal burden on ecological ecosystems. Governments influence the washing machine ecosystem by stimulating the transition to a circular economy; lifetime extension is an essential pillar in this respect.
Several types of collecting agents are responsible for the collection of washing machines. If lifetime extension is not possible, recycling centers sort, disassemble and shred E-waste. Collection agents strongly focus on achieving the legal 65% collection standard and financial goals. These goals become evident in the requirements aimed at efficient collection and return logistics. On a small scale, collection agents focus on lifetime extension. In practice, this is reflected in experimental pilots that aim to extend the lifetime of specific EEE product categories.

Furthermore, **Figure 2-3** reveals that producers, importers, and retailers all aim to collect E-waste efficiently. Profit maximization and market share are leading goals for them. The core business of these stakeholders consists of selling as many washing machines as possible. Under the influence of extended product responsibility, producers are responsible for collecting discarded washing machines. However, their collection is not integral to their core business but instead is mandated to WEEE recycling partners. Disposers of discarded washing machines require easy disposal at a collection agent. The model explicitly separates users and discarders of washing machines. Users utilize a washing machine during its technical or functional lifetime, and discarders deliver their washing machine to a collection agent.

The process step concerning the lifetime extension assessment of washing machines is currently assigned to repair facilities. Repair facilities require that a collection agent selects washing machines eligible for lifetime extension. Their goals can be traced back to profit and to extending the lifetime of significant numbers of washing machines. Indirectly, the Right to repair movement and repair information providers influence the collection process of collection agents. These stakeholders aim to select discarded washing machines for lifetime extension adequately. Their goals are aimed at encouraging the repair of EEE products rather than replacement.

In the current situation, the distribution process step is mainly aimed at recycling centers. The recycling centers are mainly driven by efficient distribution of E-waste. Because the flow of washing machines qualified for lifetime extension is still relatively small and is not distributed over a large scale, this has not been modelled in **Figure 2-3.**

In summary, the model-based analysis in **Figure 2-3** reveals that the requirements and goals of forward supply chain actors, such as manufacturers and retailers, influenced by their profit thinking, are aimed at efficient E-waste collection. Discarders want to get rid of their used electronic devices quickly and efficiently. The drivers of these stakeholders are not aimed at the lifetime extension of washing machines. Collection and life-extending process activities are externalized to collection agents, WEEE management centers, and repair facilities.

2.1.5 Collection processes and services

In this section, the collection processes and service of collection agents has been modeled. The model describes how process activities contribute to the realization of a collection service by collection agents (see **Figure 2-4**). For this purpose, the Service Realization Viewpoint in Archimate has been used. This viewpoint explains how business services are realized by business processes. **Figure 2-4** shows that the reception of discarded washing machines triggers the collection process. In practice, after being discarded by a discarder (e.g., a citizen or retailer) and transported, a washing machine is handed over to a collection agent. The processing of the discarded washing machine takes place at a collection facility. Essential process activities include: reception, registration, assessment to determine an appropriate circular strategy, sorting based on product category and lifetime extension possibility, storage in a warehouse, distribution to customers, and the generation of invoices. These activities do not necessarily have to take place in this order. Participatory observations at collection points clarify that the assessment of collected washing machines is based on tacit knowledge and experience. The current collection process does not respond adequately to the volumes of end-of-use washing machines potentially qualified for lifetime extension. The results of the assessment have consequences for sorting: at collection facilities, EEE products are sorted by product category; some collection agents also sort washing machines by brand and electronic products qualified for lifetime extension are sorted separately. The administrative process plays a vital role in realizing the collection service. A collection agent receives a fixed amount per tonnage. Governments and WEEE management collectors, who collect discarded electronics on behalf of manufacturers, are accountable for the quantity of collected EEE. This accountability is contractually arranged and must be reported periodically to the authorities and WEEE management collectors. Therefore, registering and generating invoices, mainly based on the weighed amount of E-waste tonnage, are relevant to the collection process.

The collection process leads to the realization of a collection service. This collection service consists of four stages: an invoicing service, an E-waste administration service, a distribution service, and an assessment service. The invoice and E-waste administration services, supported by administration software applications, are currently predominant services, with customers of these two services being municipal governments and E-waste processing organizations (materials recyclers). The distribution service transports discarded washing machines and other EEE to E-waste processing organizations. The invoice service then takes care of the transport payment to these E-waste processing organizations. The assessment service has repair facilities as customers, although at the moment, this assessment service has a limited scope. These assessment services become increasingly relevant under the influence of government circular economy goals.

Indirectly, it becomes clear in **Figure 2-4** that commercial stakeholders, such as producers and retailers, do not use the collection service directly in the current status quo, e.g., to harvest parts from a remanufacturing strategy and use them in a washing machine during production, or in the case of retailers that take in suitable washing machines for lifetime extension to serve its second-hand market for 'eco-friendly' customers.

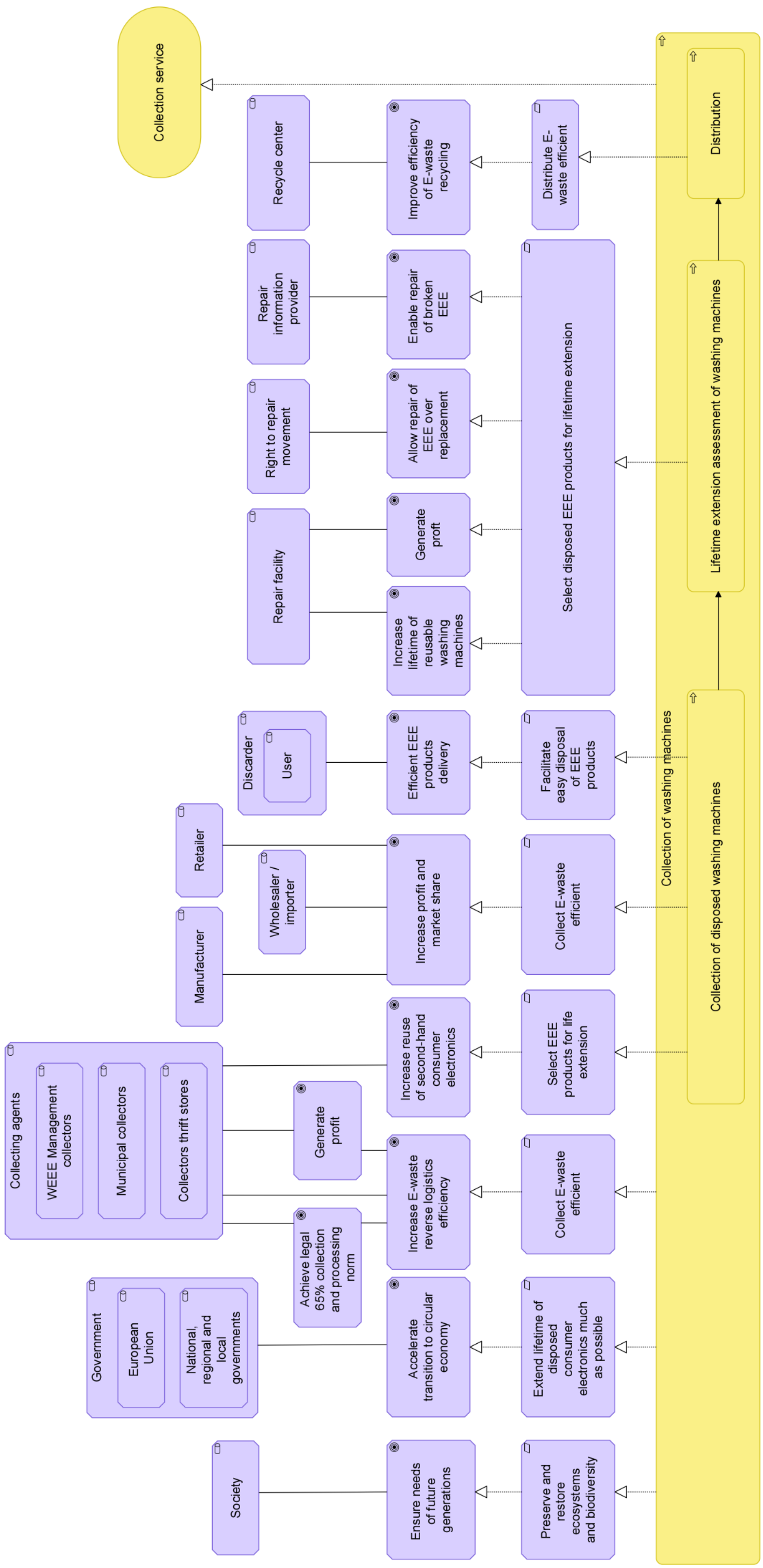


Figure 2-3: Drivers of the stakeholders in the current washing machine ecosystem

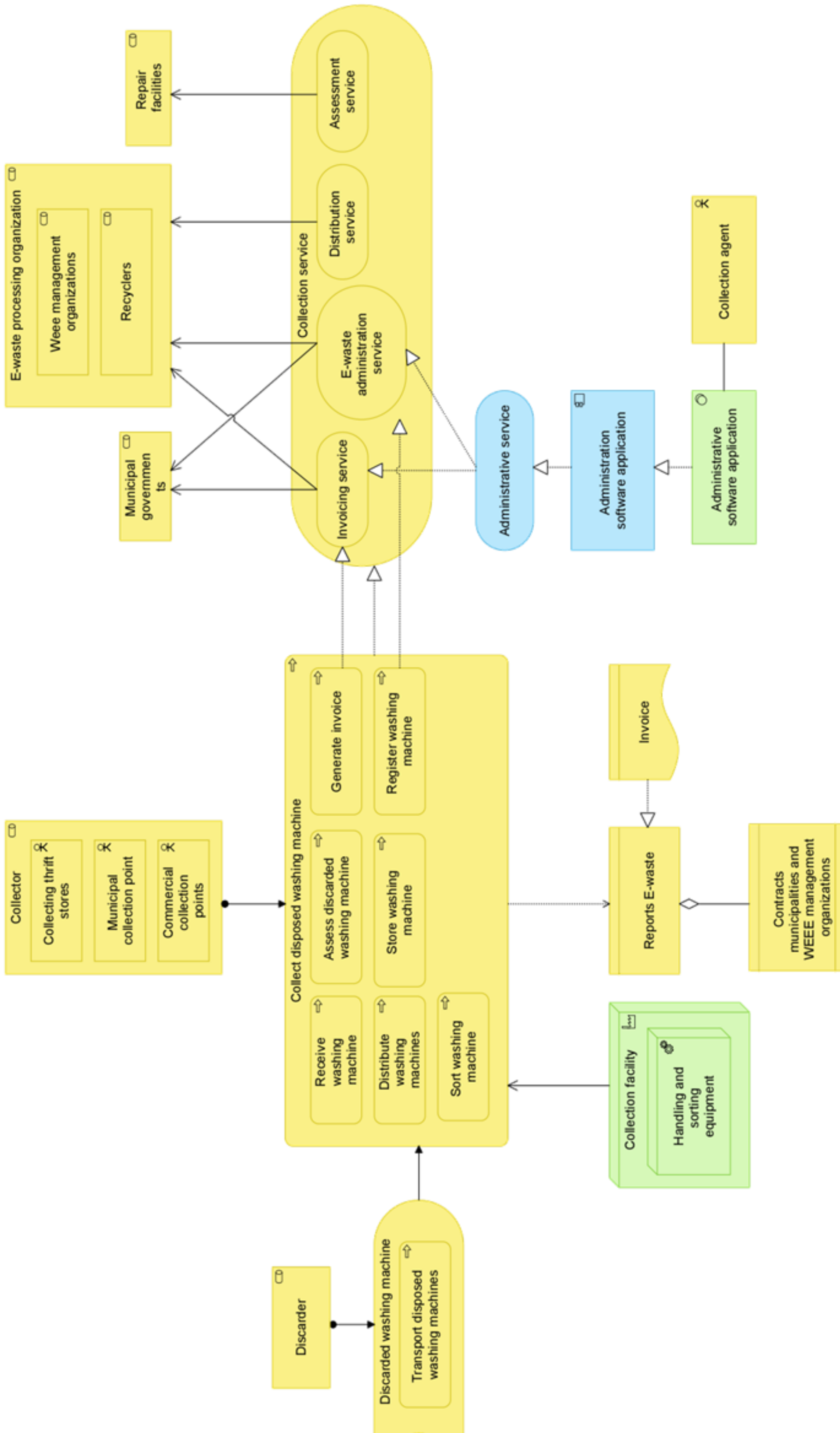


Figure 2-4: Current collection processes and services of collection agents

2.1.6 Resources and capabilities of stakeholders in the washing machine ecosystem

The goals and strategic directions of the stakeholders in the current washing machine ecosystem are realized by means of their resources and capabilities. In general, resources and capabilities enable washing machine ecosystem' stakeholders to create value for their stakeholders. This section examines how the current resources and capabilities of external stakeholders in a washing machine ecosystem contribute to the envisioned lifetime extension of washing machines. The strategy elements in the software application Archimate have been used to model the resources and capabilities of a collection agent and its external stakeholders. Resources are tangible or intangible assets owned or controlled by a stakeholder (Josey, 2017), for example, financial and physical assets, reputation, technology, and know-how. A capability is an ability that an organization possesses because of its resources and which contributes to realizing a business outcome concerning its business strategy and external environment.

Appendix A provides insight into the resources and capabilities of the most critical external business roles with an interest in a collection agent's collection service. These roles include the manufacturer, importer, retailer, government, repair facility, recycling center, B2B customer, and discarder roles. The resources and capabilities of collection agents have also been modeled. Indirect stakeholders, such as society and repair information providers, are not modeled because they do not have a direct interest in the collection agents' collection service. The government's role is, however, modeled because, based on their circular economy policy, they have an interest in a collection service that practises lifetime extension assessment of EEE products.

Appendix A also reveals that the resources of producers can be traced back to their know-how about product innovation, production, financial assets, and intellectual properties. These resources contribute to their capability to develop innovative EEE products. Importers of EEE products have a highly developed distribution capability that provides access to markets. The resources that realize this distribution capability can be traced back to the importer's logistics, marketing, and product know-how competencies. Meanwhile, the capabilities of retailers are firmly based on marketing, sales, and distribution, while their resources regarding product know-how, extensive product range, logistics, and marketing competencies contribute to realizing their capabilities.
The analysis of the resources and capabilities of producers, importers, and retailers as forward supply chain stakeholders indicates that product leadership, operational excellence, marketing capabilities, and the resources to realize these are of utmost importance. Inherent in their goals, however, lifetime extension capabilities are currently poorly developed among these stakeholders, whose strategies, goals, and business operations emphasize production, distribution, and sale of new products.

The primary capability of discarders concerns appropriate product delivery of used EEE products. Their main asset is the washing machines they own, which have economic, ecological, and social value. The capabilities of collection agents lie in collecting, sorting, transporting, and administering discarded EEE. Despite initiatives by collection agents focusing on extending lifetime on a small scale, lifetime extension assessment capabilities and the underlying resources are still overall insufficiently developed. The primary resources in question are sorting facilities, logistics, recycling know-how, and E-waste administration. The capabilities of a recycling center relate to collection, transport, materials recycling, and E-waste administration. E-waste management resources enable these capabilities. However, due to their recycling core business, lifetime extension capabilities and related resources are limited.

Lifetime extension of EEE products and product repair are essential capabilities of a repair facility. Repair facilities and the repair know-how of repairers are critical resources to realize this lifetime extension capability. Participatory observations reveal that the professionalism of repair facilities can differ significantly in practice.

B2B customers, either commercial retailers or thrift stores, have an interest in a collection service which buys EEE products whose lifetime can be extended. Their financial assets and market access know-how resources contribute to their trading capabilities.

Governments, on the other hand, play a framework-setting role in the washing machine ecosystem. Their primary capabilities are enforcement of laws and regulations, waste and circular economy policy development, and the network in which they operate. The resources to realize these capabilities can be traced back to their knowledge of waste management and the circular economy, regulations, financial assets to finance a collection service, and networking competencies. It is currently unclear to what extent governments will seek to compel and guide collection agents and their external stakeholders in their circular economy goals.

Overall, this analysis reveals that the resources and capabilities of the external stakeholders of a collection agent support, to a limited extent, the interests of a collection service that aims to extend the lifetime of washing machines. The resources and capabilities of washing machine ecosystem stakeholders are mainly based on the principles of a linear economy (see **Section 1.1.1**).

2.1.7 Lifetime extension barriers in current washing machine ecosystem

The current washing ecosystem strongly influences the extent to which extending the lifetime of discarded washing machines is possible. The analyses in the previous sections, reveal that the stakeholders in the forward supply chain negatively influence the lifetime extension activities of stakeholders in the reverse supply chain. The chance of extending the lifetime of washing machines is primarily determined by circular product design, the underlying design strategies of a washing machine, its durability, repairability, and product quality (Alfieri et al., 2018; Bocken et al., 2016; Bracquené et al., 2018). However, manufacturers do not usually design washing machines to last and indeed encourage the purchase of new washing machines (Bressanelli, Saccani, Pigosso, et al., 2020). The extent to which the design of washing machines is standardized, modular, and easy to disassemble hampers future product recovery activities (Bracquene et al., 2021). The business models of importers, wholesalers, and electronics retailers are currently transaction-driven and aim to sell new EEE products at low-profit margins (Geissdoerfer et al., 2018). Large-scale sales of second-hand washing machines have not yet been adopted. Extending the lifetime of washing machines might become more attractive if there is a significant market for second-hand EEE products. However, product innovations and market demand for affordable washing machines encourage consumers to purchase new appliances. As discarders, consumers are currently not sufficiently rewarded for delivering their used washing machines in a circular manner.

Influenced by the extended producers' responsibility, washing machine collection agents often opt for materials recycling. In contrast to lifetime extension, materials recycling is more attractive to collection agents from an economic perspective. The high costs of product repair, incurred by high spare part and labor costs, discourage collection agents and repair facilities from extending the lifetime of washing machines on a large scale. A systemic and holistic approach, where collection agents are an integral part of an EEE circular ecosystem, is currently lacking. Despite their ambitious circular economy policies, government policy promotes recycling. Despite their ambitious circular economy policy, government policy encourages recycling. Mandatory government actions to encourage stakeholders in the washing machine ecosystem to realize more life extensions of EEE products are still in their infancy.

A discriminating condition that strongly influences the possibility of lifetime extension in the collection ecosystem concerns the availability of product and usage information of washing machines for collection agents. Information sharing across stakeholders in the EEE ecosystem mainly occurs in the forward EEE supply chain (Kirchherr et al., 2018). However, the flow of information and corresponding sharing ends with customers. Reverse EEE value chain actors, such as collection and repair agents, are therefore confronted with limited availability and accessibility of information. The causes of this limited information sharing in the reverse supply chain can be traced back to the principles of a linear economy which encourage the purchase of new washing machines and empowers manufacturers through product design and product and usage information. Manufacturers, importers, and retailers have no interest in lifetime extension because it threatens the profitability of their current transaction-driven business models.

2.2 Lifetime extension assessment factors: literature review

The potential lifetime extension of washing machines depends on multiple factors (Anandh et al., 2021; Bovea et al., 2016). Designing a lifetime extension information system and assessment component for collection agents requires insight into decisive assessment factors and supportive digital trends and technologies.

2.2.1 Literature review design

A literature study was conducted to gain the necessary insight into the construction and properties of a washing machine. An outline of the washing machine market has also been explored. Subsequently, potential assessment factors that affect the lifetime of washing machines have been identified. These factors were determined based on participatory observations, interviews, and document analysis. The participatory observations and interviews took place at the technical workstations of washing machine repairers and revealed critical technical factors that influence the lifetime extension of washing machines. Interviews at thrift stores and retailers selling consumer electronics provided further knowledge of relevant washing machine market factors. Circular economy and government digitization policy documents were analyzed in exploratory document analysis and provided guidance on environmental aspects, digitalization, and DPPs. These research activities led to the identification of assessment factors and relevant digital development affecting the lifetime extension possibilities and assessment of collected washing machines. Based on these factors, a systematic search strategy has been defined. The "ScienceDirect" and "EBSCO host" databases were used during the literature study to find helpful scientific articles on lifetime extension assessment factors. Relevant search terms were: "Washing machines," "Washing machine statistics", "Circular product design", Eco-design", "Circular design", "Sustainable design", "Design for sustainability", "Life cycle design", "Durability", "Product lifetime extension", "Lifetime", "Failure modes", "Repairability", "Repair", "Energy Labelling", "Energy efficiency", "Life cycle assessment", "Environmental impacts", "Digital circular economy", "Digitalization", "Smart appliances", "Internet of Things", "Industry 4.0", "Artificial intelligence", "Digital product passports", "Decision support system", and "Decision making". The databases were searched for literature between 2017 and 2022 to guarantee the topicality of the articles and research findings. The search strategy eventually led to the selection of 131 articles. After reading the abstracts for the article’s relevance, 72 articles were selected for the literature review, all of which have been thoroughly read. The following sections elaborate on the literature review results.

2.2.2 Construction and properties of washing machines

A washing machine is "a machine which cleans and rinses textiles using water which also has a spin extraction function and which is designed to be used principally for non-professional purposes" (Boyano et al., 2017, p. 10). The definition makes it clear that the primary function of a washing machine is to clean, rinse and spin clothes. The objective of the cleaning process concerns restoring the fitness for use and aesthetic properties of the textiles being washed (Terpstra, 2001). According to the principles of the Sinner circle (Hauthal, 2012), the laundering procedure is determined by chemical action (cleaning agents), time (length of washing program), the temperature of the water, and mechanical action of the washing machine (speed of rotation of the drum). These parameters are interdependent and must be balanced to achieve a satisfactory washing result. Multiple configurations of the parameters in the Sinner circle are possible, e.g., by extending the time of a washing program, the water temperature can be lowered, or by adding more detergents, washing program times will shorten. In addition to cleaning, rinsing, and spinning, a washing machine has secondary functions, such as automatic detergent dosage, adapting the spin speed, and remote control (Bracquené et al., 2018).

Different types of washing machines can be distinguished from the literature: the front loader, the top loader, or the washer dryer combination. The most common type of washing machine in Dutch households is the front loader (Bracquené et al., 2018). A washing machine has different programs according to the type of laundry. In addition to the washing programs, a machine can have features such as water damage detection, drum cleaning, hot water connection, and start delay. Internet of Things applications on washing machines enable remote control and service, diagnostics data generation, and firmware updating (Bressanelli et al., 2017). The washing machine market has various configurations (Bracquené et al., 2018a): washing machine manufacturers regularly release new product types with innovative product features. The load capacity of washing machines is between 5 and 10 kilograms. Their energy efficiency continues to improve. Machines must comply with the energy efficiency standards laid down in EU legal frameworks, such as "Regulation on ecodesign requirements for household washing machines and washer-dryers (EU) 2019/2023" and "Regulation on energy labeling for household washing machines and washer-dryers (EU) 2019/2014". The energy efficiency classification on the energy label for washing machines will have been renewed in 2021 to make room for even more energy-efficient appliances. The value on the energy label for washing machines is based on the energy consumption of a washing machine on an Eco washing program at 40-60 degrees. The water consumption of washing machines has been reduced over the past decade.

The different parts of washing machines work together to perform the primary and secondary functions. As summarized by (Alfieri et al., 2018), a washing machine often contains the following parts: drum & tub, motor, tacho generator, drive belt/pulley, heater & thermostats, pressure chamber, level control, shock absorbers, bearings, hose (inlet/outlet), aquastop system, valves, detergent drawer, door (handle/hinge/lock/seal), gasket, drain pump, and electronics (control/engine/programs).

2.2.3 Washing machine market analysis

The Statista database provides insight into market and consumer data[1]. The following washing machine market analysis is based on this database.

Washing machines are Europe's most traded home appliance, with 25.4 million units traded. In the Netherlands, 706,000 washing machines were sold in 2021, while in 2013, the number of washing machines sold was 576,000. In 2021, 92% of Dutch households owned a washing machine, the preferred brands of which in Dutch households in 2022 were Bosch, AEG, Miele, and Samsung (see **Table 2-2)**. The data suggested that German brands dominate the washing machine market in the Netherlands. The average price for a washing machine was 560 euros in 2018. In 2020 this average price had increased to 595 euros. Research in Germany by Hennies and Stamminger (2016) shows that 10% of respondents bought a low-cost washing machine, 54% bought a medium-price washing machine, and 27% bought an expensive top-brand washing machine. 76% of respondents indicated that they bought a new washing machine, while 23% of respondents bought a used one. Furthermore, research by Hennies and Stamminger (2016) revealed that 21% of respondents, before discarding, used their washing machine once a week, and 66% of respondents used it several times a week. This statistic displays the average number of washes per person per day in the Netherlands from 1992 to 2016. On average, respondents to this survey in 2016 performed 0.24 washes per day. 31% of washing machine users use their machine below its weight capacity limit.

[1] Source: https://www-statista-com.saxion.idm.oclc.org/statistics/1061278/washing-machine-sales-in-the-netherlands/

The global market size for smart washing machines is expected to increase in the coming years. In 2022, this market size was 17.5 billion US dollars, and it is expected to climb to 37.9 billion US dollars by 2028. In 2022, 10% of Dutch households owned a smart electrical appliance. In the near future, an increase in the market for smart washing machines can be expected in the Netherlands.

Brand	Percentage
Bosch	17%
AEG	15%
Miele	13%
Samsung	13%
LG	7%
Siemens	7%
Whirlpool	6%
Beko	5%
Other	17%
Total	100%

Table 2-2: Washing machine ownership by brand in the Netherlands in 2022 (source: Statista.com)

2.2.4 Washing machine design strategies

In addition to product durability and related repairability, product design strategies significantly influence material efficiency (Moreno et al., 2016; Stamminger et al., 2018). In a circular economy, consumer electronic products should be designed to guarantee long-term value retention and utilize possible circular business model opportunities (Bocken et al., 2016). Current repairability problems in consumer electronics have their origin in poor design assumptions. Designers should, therefore, rethink the design process and strategies to reflect the principles of a circular economy in their designs. Circular product design “Elevates design to a system level (1), Strives to maintain product integrity (2), Is about cycling at a different pace (3), Explores new relationships and experiences with products (4), and is driven by different business models(5)” (Bakker et al., 2014). The preservation of the economic and environmental value of materials for as long as possible in the economic system by slowing down the flow of resources or closing the loop by recycling materials is closely related to product design in a circular economy (Bocken et al., 2016; Den Hollander et al., 2017). Based on the product integrity principle (see **Section 1.1.3**), circular product design should prevent a product from becoming redundant. Obsolete products awaiting recovery should be recovered with the highest level of product integrity, at the level of products and components (Design for Product Integrity) or, if not possible, at the level of materials (Design for Recycling). According to Bocken et al. (2016), design strategies to slow resource loops are related to the design of long-life products (design for attachment and trust and Design for Reliability and Durability) and Design for Product Lifetime Extension (Design for Ease of Maintenance and Repair, Design Upgradability and Adaptability, Design for Standardization and Compatibility and Design for Dis- and reassembly). Other design strategies for slowing resources loops concern Design for Maintenance and Design for Upgrading (Den Hollander et al., 2017), Design for Dematerializing products, for example, by Design for Product-Service System or Design for Sharing, or Design for Resource Recovery, such as Design for Cascade Use and Design for Remanufacturing (Moreno et al., 2016). In line with the Energy labeling Directive, the EU Eco-design Directive states that the product design of energy-consuming and energy-related products such as washing machines must meet environmental protection requirements to reduce energy consumption, reduce adverse environmental effects during the product life cycle and promote lifetime extension. The latter by making durable and repairable products for consumers that are energy and water efficient.

2.2.5 Durability and failure modes of washing machines

The durability of a washing machine is highly dependent on its ability to last. According to (Alfieri et al., 2018) durability is "the ability to function as required over time under defined conditions of use, maintenance and repair until a limiting state is reached." The lifetime of washing machines depends on factors such as mechanical stress, abrasion, performed maintenance activities, new technologies, aesthetics, energy efficiency, and environmental conditions (Prakash et al., 2020; Tecchio et al., 2019). In this case, a technical lifetime is related to the reliability and resistance of washing machines until defects occur. According to Tecchio et al. (2019), the average service lifetime of an unrepaired washing machine is 12.6 years, with an interquartile range between 6 and 18 years. In Germany, the average washing machine lifetime was 12.7 years in 2004, 12.4 years in 2008, further decreasing to 11.9 years in 2012/2013 (Prakash et al., 2020). 20% of discarded washing machines were newer than five years old, and 50% were newer than ten. 50% of the users revealed they had never repaired their washing machines. In the Netherlands, the average age of a washing machine was 11.7 in 2005 (Bakker et al., 2014). Under the influence of technological innovations, the average lifetime of washing machines has further shortened over the past decade. **Figure 2-5** shows that the lifetime of high-quality washing machines is longer than low- and medium-priced washing machines (Hennies & Stamminger, 2016). In addition to the purchase price, the age of a washing machine is also primarily determined by usage frequency. Besides the foreseen technical lifetime, daily use of a washing machine significantly reduces its lifetime. Mechanical, thermal, and chemical stress during use affects the lifetime of washing machines (Stamminger et al., 2020). Washing machine parts that vibrate under mechanical stress, such as the tub-drum system, and other corresponding parts, such as the motor and shock absorbers, often break down.

Reasons for users discarding their washing machines can be traced back to factors such as whether a device is technically defective, or users no longer appreciate the device. One user might not be satisfied because certain features are lacking, while another user replaces a device because it is not energy efficient, or, indeed, for other reasons (Hennies & Stamminger, 2016). Their washing machine having come to the end of its technical lifetime was the main reason for 69% of users to discard their device. In 90% of washing machines sold, there was a replacement demand by the buyer (VHK, 2014), whereas product lifetime extension strategies, in line with the principles of a linear economy, were not considered. 78% of consumers chose not to repair a washing machine if it is broken (Tecchio et al., 2019). Washing machine users often expected washing machines to last longer compared to other EEE products and therefore do not see product repair as an option. 15% of broken washing machines were not repaired due to insufficient technical feasibility. Repair is not economically viable for 7% of unrepaired washing machines.

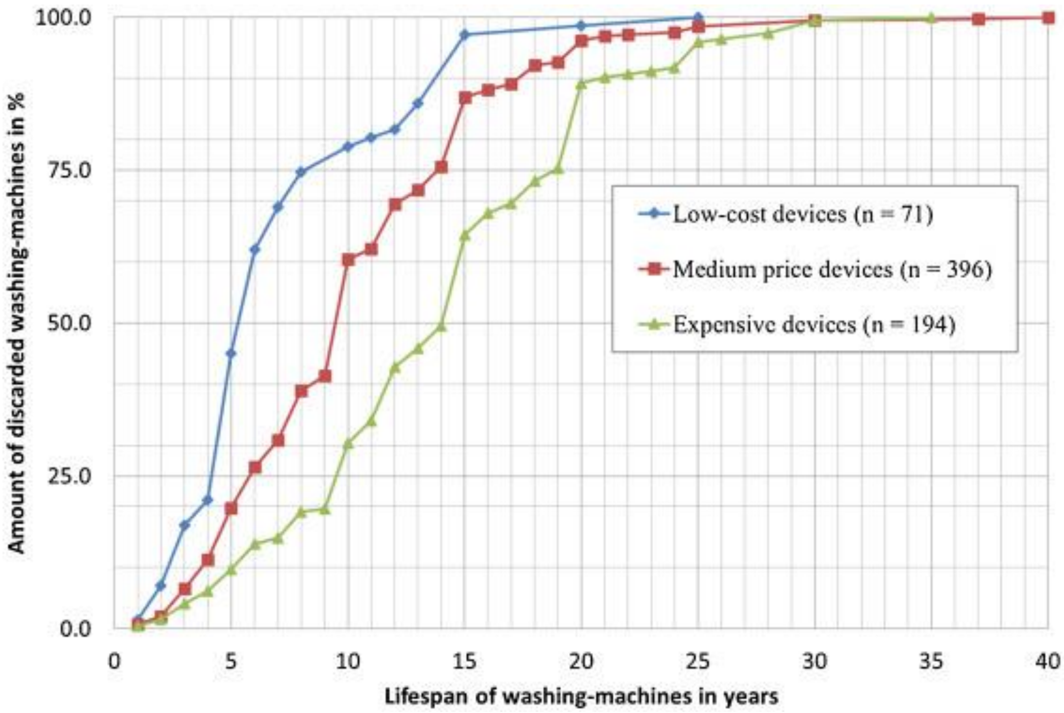


Figure 2-5: Discarded washing machines differentiated by price versus age (Hennies & Stamminger, 2016, p. 74)

Furthermore, research by (Hennies & Stamminger, 2016) showed that the age of a washing machine is shorter in younger respondents compared to older respondents, 9.7 and 12.6 years, respectively. Increasing levels of user satisfaction closely correlate with an increasing lifetime of washing machines. Lifetime expectations and actual lifetimes increase as the purchase price of a washing machine increases (Stamminger et al., 2020). Furthermore, common failure modes in washing machines are mostly related to electronics, shock absorbers, bearings, doors, carbon brushes in engines, pumps and the presence of foreign objects (Tecchio et al., 2019). All washing machine parts are sensitive to failure (Prakash et al., 2020).

2.2.6 Repairability of washing machines: literature review

Analysis of the potential reuse of disposed of EEE products requires technically oriented methodologies that provide insight into the functioning of a device (Bovea et al., 2016). Visual inspection, functional tests, safety tests, and reuse protocols are part of such a methodology (Johnson et al., 2020). International standards such as PAS 141 (Bovea et al., 2016) specify performing tests which aim to objectify the reusability of a washing machine. These visual, safety and functional tests vary considerably in complexity and execution time. In addition to technical assessments of washing machines, it is essential to consider their repairability. Lifetime extension of washing machines strongly depends on their repairability (Tecchio et al., 2019) and the product quality of the machine itself. Repairability is the ability and ease with which a product can be repaired during its life cycle (Flipsen et al., 2016). In a repair process, several repair steps and related repair activities are performed (Bracquené et al., 2018):

- Repair step 1: Provision of information concerning the identification of product model, product information, failure diagnostic, disassembly and reassembly, availability of spare parts, replacement, and restoring to working condition (e.g., exploded view diagrams, repair manuals and disassembly instructions). The availability of support services to provide product information is relevant here.
- Repair step 2: Identification of the damage or failure, whereby an assessment of the technical repairability and necessary further repair actions can be determined (e.g., the replacement of failed parts).
- Repair step 3: Ease of disassembly and reassembly to identify faults and replace components or modules.
- Repair step 4: Spare part replacement encompassing the availability, accessibility, and cost of spare parts and a compilation of priority parts.
- Repair step 5: Restoring the electronic device to working condition.

The complexity of these repair steps determines the suitability of a washing machine for lifetime extension. Cordella et al. (2018) developed a generic multi-level approach to assess the repairability of energy-related products. Level 1 relates to a qualitative assessment of the product design utilizing a checklist and the desired repair conditions (e.g., the accessibility of parts, identification of priority parts, and the required technical repair skills). At level 2, the degree of repairability is scored by a semi-quantitative assessment of product-specific parameters and score rubrics. Differentiation is possible by including different repairability parameters and weights in the assessment. Level 3 quantifies the repairability scores according to technical indicators (e.g., time to disassemble or duration of availability of spare parts provided by manufacturers).

Furthermore, quantitative methods are available for assessing the repairability of energy-related products, such as the Assessment Matrix for ease of Repair (Bracquené et al., 2018), the Repair Scoring System (Cordella et al., 2019), and the French repair index (REPAIR.EU, 2021) (see **Table 2-3**). Many of the assessment criteria in the three methods are similar, such as information availability, disassembly aspects, and spare parts costs.

The ease of assembly and disassembly of electronic products is measured for all three methods, as well as the availability and price of priority spare parts. The French repair index differs from the RSS and Assessment Matrix for ease of Repair by also including parameters related to product-specific criteria, such as assistance and the possibility of resetting the software of electronic products. Several rubrics relate to each parameter to which a score is assigned. The accumulation of the different scores in a worksheet leads to an objectified repairability score. This repairability score provides users with information about the repairability of consumer electronic devices. Calculating the Repairability Score as proposed in the AsMeR methodology can be significantly reduced to a limited set of parameters: instruction regarding failure modes, disassembly guidance, ease of disassembly, modularity, availability of repair service, and spare part supply cost (Bracquene et al., 2021).

Assessment Matrix for ease of Repair (Bracquené et al., 2018)	Repair Scoring System (Cordella et al., 2019)	French repair index (REPAIR.EU, 2021)
Information provision: 1. Ease of identification 2. Instructions for problem identification 3. Disassembly instructions 4. Information for spare parts 5. Information for 3D printing of spare parts 6. Instructions for reconditioning of product *Product design for repairer:* 1. Accessibility of identification 2. Robustness of identification 3. Product designed for easy failure detection 4. Product designed for ease of disassembly 5. Required tools for disassembly 6. Modular design of the product 7. Standardized design 8. Product designed for ease of restoring to working condition after repair *Services offered by the manufacturer:* 1. Support service availability 2. Support service duration 3. Support service accessibility 4. Spare part supply content 5. Spare part supply accessibility 6. Spare part supply cost	1. Disassembly depth/sequence 2. Fasteners 3. Tools 4. Disassembly time 5. Diagnosis support and interface 6. Type and availability of information 7. Spare parts 8. Software and firmware 9. Safety, skills and working environment 10. Data transfer and deletion 11. Password reset and restoration of factory settings 12. Commercial guarantee	1. Documentation 2. Disassembly, Accessibility, Tools, Fasteners 3. Availability of spare parts 4. Price of spare parts 5. Product Specific criterion: accessibility of usage-counter to consumers, free remote assistance, possibility to reset software

Table 2-3: Quantitative repairability assessment methods for energy related products

In addition to the repairability score of a washing machine, the repair rates of specific breaking parts guide the feasibility of possible repair activities. Research by (Tecchio et al., 2019) shows that around 70% of defective washing machines have a single failure mode. 30% of washing machines have multiple failure modes. According to Tecchio et al. (2019), at the initial diagnosis stage, 43% of repaired washing machines had not previously been repaired. 47% of the appliances had already been repaired once before. Such previous repairs limit the repairability of washing machines. The highest repair rate is possible for washing machine parts, doors, carbon brushes, and foreign objects. Bearings, drums, tubs, circulation pumps, and electronics have a low repair rate due to the complexity of their repair and high spare part replacement costs.

2.2.7 Environmental impact of washing machines

From a life cycle perspective, the durability of washing machines is beneficial for maximum resource efficiency (Stamminger et al., 2018). Among repairers there is a tendency to extend the service life of EEE products that fail before the end of their projected lifetime (Bovea et al., 2020). However, life time extension is not the best circular strategy in all cases (Ardente & Mathieux, 2014). Besides technical factors, an environmental impact assessment should be carried out to assess the possible lifetime extension of energy-using EEE products (Bovea et al., 2018). For washing machines, water and energy efficiency overwhelmingly determines environmental impact (Pakula & Stamminger, 2015). Encouraged by national incentive programs, users tend to replace existing high energy consuming EEE products with energy-efficient devices (Alejandre et al., 2022). The assumption here is that energy-efficient devices have less impact on the environment but that they do not address the question of what an optimal lifetime to reduce the greenhouse gas emissions of EEE products is. Electrical energy consumption also depends on factors such as the year of manufacture of the washing machine, energy efficiency class, and responsible usage behavior, such as temperature and the duration of a washing program (Milani et al., 2015). Such ecological considerations require a life cycle analysis approach in which the environmental impact in all phases of an EEE product, from raw material extraction to recycling, is assessed on quantified CO2 emissions for the whole life cycle (Okumura, 2022; Omer, 2009; Park et al., 2006). The electrical consumption of EEE products in the usage phase contributes most to greenhouse emissions (Alejandre et al., 2022; Stamminger et al., 2018). Indeed, according to Alejandre et al. (2022), A-class washing machines with an assumed average lifetime of 10 years can reduce kg CO2-eq/lifetime by 59.8-76.2%. This percentage can be traced back to a renewable energy mix during the use phase and an energy consumption reduction by users of 10%. The study further reveals that renewable sources of electricity and responsible consumption bring the most significant environmental benefits compared to material efficiency and the use of recycled materials in production. In the LCA scenarios where 100% renewable energy is assumed in the LCA analysis, replacing a washing machine is theoretically, from a sustainability perspective, relevant after 28 years. Responsible consumption patterns can stretch this number to 33 years. This LCA study does not, however, consider the maximum technical product life of EEE products, which is often shorter.

Furthermore, there are LCA scenarios that aim for material reduction and the use of recycled resources during the production of new washing machines, but if no renewable energy resources are available during the use phase, the washing machine should, from a sustainability perspective, be replaced after 4.6 years. Thus, the renewable energy mix during the use phase and a reduction in energy consumption are discriminating factors in determining the Global Warming Potential. Although environmental impact is mainly generated in the use phase, durable, energy-efficient EEE products in the use phase require a shift in the production phase (Stamminger et al., 2018). A study by Chen et al. (2017) shows that besides the usage phase, the carbon emission contribution of washing machines is also significant in the material phase. Additionally, recycled and lightweight materials diminish the need for virgin raw material extraction and reduce E-waste streams (Alejandre et al., 2022).

2.2.8 Digital technologies

Digital technologies are a fundamental enabler of the transition toward a circular economy (Antikainen et al., 2018; Peiró et al., 2021; Ranta et al., 2021). Digitalization makes it possible to access and share relevant information with value chain actors during the product life cycle (Hedberg & Šipka, 2021). Promising examples of Industry 4.0 digital technologies are the Internet of Things, Machine Learning, Artificial Intelligence, Big Data Analytics, Digital Twins, Robotics, Cloud Computing, Augmented Reality, and Radio Frequency Identification (Shah et al., 2022). Industry 4.0 strives for end-to-end connectivity, lower cost, higher quality, and improved performance. Digital technologies provide insight and understanding at all phases of the product's lifetime, such as design, production, maintenance, redistribution, and repair (Ertz et al., 2022b). Digital technologies also contribute considerably to the design innovation of products and components (Saarikko et al., 2017) and allow data-oriented predictive maintenance services (Aheleroff et al., 2020; Bressanelli et al., 2017). Smart washing machines generate a continuous data stream that provides insight into the functional status of devices, user behaviors, the condition of parts, energy consumption, and predictive maintenance.

Insight into a product at all of its life cycle phases increases the chance of applying product lifetime extension strategies and the exclusion of end-of-life treatments. Internet of Things applications in devices allow seamless communication with digital devices in communicating-actuating networks (Alaa et al., 2017; Gubbi et al., 2013). The increase in Internet of Things (IoT) technologies will thus fundamentally change the washing machine industry (Bressanelli et al., 2017; Saarikko et al., 2017). Internet of Things applications offer companies opportunities to innovate their business models through the provision of information on products, location, status, and availability by adding value-added services from a network of intelligent devices (Ghoreishi & Happonen, 2020; Lee, 2019; Leiting et al., 2022; Suppatvech et al., 2019). Digital business models can contribute to improving circularity in value chains and create unique value creation and value capture (Ranta et al., 2021).

2.2.9 Digital product passports

As part of general ecodesign requirements, the EU Green Deal Action plan sees digitization of product information throughout the entire product life cycle as an enabler towards a circular economy (Götz et al., 2022; Krämer, 2020). DPPs contain unique product identifiers allowing data storage, retrieval, and sharing by various value chain actors throughout the product lifecycle (Saari et al., 2022). A DPP can be defined as a "product-specific data set, which can be electronically accessed through a data carrier to electronically register, process and share product-related information amongst supply chain businesses, authorities, and consumers" (European Commission, 2021). The information in the passport relates to the product's environmental sustainability and is, therefore, an enabler for resource-efficient, sustainable, and circular production and consumption systems (Adisorn et al., 2021; Walden et al., 2021). DPPs facilitate sustainable product life cycle management and value retention in a circular value chain (Berger et al., 2022). The passports support the development of products that are durable, reliable, reusable, upgradable, repairable, energy and resource-efficient, and easier to maintain, refurbish and recycle (European Commission, 2019). DPPs are especially attractive for high-value EEE products that have a long service life.

The digitization of product information in DPPs has multiple benefits for value chain actors. The information in the DPPs contributes to fact-based transparency of product sustainability for businesses and governments, supports consumers in making informed and sustainable purchasing decisions, stimulates the development of new business models, contributes to resource optimization, enables objectified sustainability reporting and auditing based on sustainability indicators and contributes to EEE product transparency and traceability in a value chain (Götz et al., 2022). According to Götz et al. (2022), DPPs, as single points of truth, support high-quality end-of-use circular strategies. The reuse of products can be determined more accurately because the data in a DPP will objectify the residual product value. Repair and maintenance can be better predicted and programmed over time based on the data in the DPP. Detailed technical, repairability, product, usage, and spare parts information contribute favorably to lifetime extension services provided by repairers and maintenance service providers (Saari et al., 2022). Insight can be gleaned into use, wear and tear, repairability of products, and parts support refurbishment strategies. Remanufacturing becomes possible because the data provides insight into the quality of parts apt for reuse in new products. Implementing such high-quality circular strategies has consequences that require the availability and accessibility of substantive information in a DPP and its underlying information systems (Adisorn et al., 2021; Plociennik et al., 2022).

Inherent in the intended information sharing in EEE value chains, the application of DPPs requires consideration of issues such as access control, inclusivity, flexibility, and data quality (Saari et al., 2022). Access control addresses which value chain actors have access rights to data, to what extent they can modify, add and update data, and at what level data aggregation is required. The tension between data sharing and data protection due to business confidentiality plays a crucial role. The inclusivity criterion strives for low costs and limited technical barriers, allowing all value chain actors to access a DPP (Götz et al., 2022).

Informed decision-making across the value chain requires accurate and verifiable data. Data governance contributes to data management policies, processes, and standards, increasing the value of data and its exchange across value chain actors (Abraham et al., 2019) according to the FAIR data principles (Wilkinson et al., 2019). The elaboration of DPP information requirements addresses strategic questions on which information is recorded in a DPP, which use cases are supported by a DPP, who the primary sources of DPP information are, how IoT-equipped products will interact with the DPP, and how Life cycle analysis calculations are integrated into a DPP (Götz et al., 2022; Saari et al., 2022).

2.3 Repairability of washing machines: practical experiences

As explained in the previous section, the repairability of a washing machine largely determines the extent to which lifetime extension is possible (Bracquené et al., 2018; Bracquene et al., 2021). In addition to the theoretical exploration in **Section 2.2.5** and **2.2.6** on the durability and repairability of washing machines respectively, this section outlines the practical experiences of washing machine repairers. As a preliminary to developing a lifetime extension assessment component, far-reaching insight must be obtained from the perspective of repairers into common failure modes and the repairability of washing machines. The expertise of repairers provides the starting point for identifying critical washing machine-related factors that are decisive in assessing whether lifetime extension is possible. For the aspect of washing machines failure modes, the theoretical insights are compared to the practical experiences of repairers.

2.3.1 Research design

Semi-structured interviews were conducted with four professional repairers who, in addition to washing machines, also repair other EEE products. Three commercial repairers are employees at commercial retailers providing repair services and selling new EEE products. One repairer is the head of a thrift store's technical workshop and repair cafe. The interviews aimed to gain an understanding of the frequent failure modes of washing machines encountered by repairers and their estimated repairability. Relevant interview topics in the questionnaire include repairability aspects, such as brand, diagnosis time, accessibility of critical washing machines' parts, ease of disassembly, repairability time, required repair expertise, spare parts availability, and product and repair information.

2.3.2 Failure modes of washing machines

Insight into common failure modes of washing machines is relevant because this is related to the extent to which lifetime extension is feasible. For example, broken washing machine motors or electronics are difficult to repair while a broken pump filter is easy to repair. Every repairer was asked what the most common failure modes for a washing machine are. According to information provided by the repairers, **Table 2-4** presents the most common washing machine failure modes. The table also outlines the theoretical results of a large-scale study regarding the frequency of washing machine failure modes (Tecchio et al., 2019).

Table 2-4 illustrates that most failure modes in non-functioning washing machines can be traced back to electronics, the door, the pump and pump filter, and foreign objects. Because of their unique repair experiences, which may vary by washing machine brand, the table clarifies that common failure modes mentioned by repairers differ on a few points. For example, one repairman indicated that the heating element of a washing machine often breaks down, while other repairers do not mention this as a frequent failure mode. Furthermore, the repairers indicated that, in addition to these frequent failure modes, they also diagnosed malfunctioning bearings, shock absorbers, and carbon brushes. Two repairmen indicated that the new generation of washing machines has brushless motors, which means that this failure mode will occur less often in the future. The failure modes reported by repairers coincide with the identified failure modes in the theoretical study by Tecchio et al. (2019).

Failure modes	Obbink	RTV Stegeman	Expert	Foenix	Tecchio et al. (2019)
1. Bearings	X		X		X
2. Electronics	X	X	X		X
3. Door	X	X	X		X
4. Pump	X	X	X		X
5. Pump filter	X			X	
6. Inlet valves			X	X	
7. Drain system				X	
8. Heating element			X		
9. Shock absorbers		X		X	X
10. Foreign objects	X	X		X	X
11. Switches		X			
12. Detergent system		X			
13. Carbon brushes			X	X	X
14. Drive belt				X	

Table 2-4: Most frequent failure modes in washing machines

One repairer indicated that the broad application of electronics and digital technologies in current washing machines increased their sensitivity and vulnerability. The repairers also revealed that users' misuse of the washing machines caused defects, for example, low washing temperatures, drum overload, excessive detergent usage, lack of periodical internal cleaning of the washing machine, and rough treatment of laundry in the drum. One repairman indicated that the pump often breaks down due to wear, and defective pump filters are often clogged.

2.3.3 Single and multiple failure modes of washing machines

In one interview, a single repairer was asked to investigate single or multiple failure modes. In line with the findings of Tecchio et al. (2019), the repairer indicated that most failure modes in washing machines occur singly (see **Table 2-5**). **Table 2-5** shows that frequent defects are related to electronics, bearings, doors, and pumps take place in isolation. **Table 2-6** presents the failure modes that, according to the repairers, often occur in combination. However, not every failure mode of a washing machine automatically is part of a combination of several failure modes.

Table 2-6 shows that a broken pump is often caused by a foreign object in the washing machine and defects in the drain system. It is also possible that a defective pump is caused by malfunctioning inlet valves. Non-functioning electronics are often associated with a defective control panel and related control buttons. According to the repairmen, broken shock absorbers are often the result of non-functioning bearings.

Possible failure modes of washing machines	Single failure mode
1. Electronics	X
2. Shock absorbers	X
3. Bearings	X
4. Doors	X
5. Shock absorbers	
6. Pumps	X
7. Foreign objects	X
8. Engine	
9. Drain system	
10. Inlet valves	X
11. Switches	X
12. Drive belt	
13. Pump filter	X
14. Drum and tub	
15. Heating element	X
16. Pressure control	
17. Detergent system	X
18. Cables and plugs	
19. Others	

Table 2-5: Single failure modes

Primary failure	Related failure modes
Electronics	Switches
Pump	Foreign objects Drain system Pump filter
Pump	Inlet valves
Bearings	Drum and tub
Shock absorbers	Bearings

Table 2-6: Frequent combinations of multiple failures models

2.3.4 Repairability differentiated by brands

All four repairers were asked to what extent repairability depends on the brand. All respondents indicated that German brands are the most repairable. According to the repairers, German washing machines use high-quality materials that contribute favorably to their repairability. However, two repairmen noted that German washing machines are produced abroad, and, as such, these appliances may have a lower product quality. They also indicated that within the German brands, product quality can differ per market segment. According to the repairers, it is often difficult to determine the market segment where washing machines can be positioned over a more extended period. This vagueness arises from the large quantities of product types that washing machine manufacturers put on the market.

The respondents were pessimistic about 'cheap' brands (such as LG, Indesit, and Candy) because these machines are not constructed to last long and have poor repairability. Likewise, Samsung washing machines break down quickly, e.g., within five years. According to the respondents, the repairability of

Samsung washing machines is often not an option due to their low product quality. One respondent noted that Samsung parts are also difficult to obtain.

2.3.5 Diagnosis time

Diagnosing a washing machine failure mode takes time, and the time required influences its repairability (Cordella et al., 2019). Respondents one, two, and three were asked to estimate the diagnosis time for the common defects listed **in Table 2-7** for the failure modes of washing machines they regularly encounter.

	Estimated diagnosis time (in minutes)		
Failure modes	**Obbink**	**RTV Stegeman**	**Expert**
1. Bearings	<5		5
2. Electronics	20	10	20-30
3. Door	5	5	<5
4. Pump	10-15	25	15-20
5. Pump filter	5		
6. Inlet valves			<5
7. Heating element			10-15
8. Shock absorbers		5	
9. Foreign objects	15	5	
10. Switches		25	
11. Detergent system		5	

Table 2-7: Estimated average diagnosis time of frequent failure modes

Table 2-7 shows that diagnosing the condition of bearings, door-related failure modes, pump filter, shock absorbers, foreign objects, and the detergent system takes 5 minutes or less. According to the repairer, diagnosing electronics failure modes varies between 10 and 30 minutes. Searching for a foreign object in a washing machine might take a relatively long time. Diagnosing a failure mode is easier for the new generation of digital washing machines because these devices can be connected to a computer to provide maintenance and repair information. At the same time, the repairers indicated that even though a diagnosis can be performed digitally, it still requires technical knowledge to confirm the failure mode and find the deep root causes.

2.3.6 Accessibility of parts

The accessibility of spare parts for a washing machine affects diagnosis and repair time (Bracquene et al., 2021; Cordella et al., 2019). Repairers 1, 2, and 3 were asked to indicate, based on their practical experience, the accessibility of critical washing machine parts (see **Table 2-8**).

The repairers noted that specific situational factors might influence the scores presented in **Table 2-8**. More easily accessible spare parts, according to the repairers, include electronics, and the pump filter. Two repairmen indicated that related parts are easily accessible, and one repairman experienced difficulties with the accessibility of the cuff. According to the repairman, the drum size complicates the accessibility of the cuff. Another repairman, on the other hand, indicated that the cuff is easily accessible but refers only to the front part of the cuff. Repairer one indicated that related issues, such as the door hinge and suspension, are easily accessible. Limited accessibility of washing machine parts relates to the bearings and shock absorbers. Moderate ease of accessibility, according to the repairers, applies to switches, inlet valves, the heating element, and foreign objects.

Failure modes	Obbink	RTV Stegeman	Expert
1. Bearings	1		1
2. Electronics	3	5	5
3. Door	5	4	2
4. Pump	4	3	3
5. Pump filter	5		
6. Inlet valves			4
7. Heating element			4
8. Shock absorbers		2	
9. Foreign objects	4	3	
10. Switches		3	
11. Detergent system		4	

Table 2-8: Ease of accessibility of spare parts in frequent failure modes (1 = very difficult, 2 = difficult, 3 = not difficult, not easy, 4 = easy, 5 = very easy)

2.3.7 Ease of disassembly

In addition to accessibility, ease of disassembly significantly impacts the repairability of washing machines (Vanegas et al., 2018). Disassembly is “a reversible process in which a product is separated into its parts by non-destructive operations or semi-destructive operations which only damage the connectors/fasteners in such a way that it could subsequently be reassembled and made operational, possibly needing new connectors/fasteners.” (Bracquené et al., 2018, p. 18). The ease of disassembly can be operationalized in the number of steps required to remove a part from a washing machine and the time required for each step (Bracquené et al., 2021). The interviewed repairers were asked to make a relative estimate of the ease of disassembly to reach a specific washing machine part that frequently presents a failure mode (see **Table 2-4**)

Table 2-9 shows that the disassembly of bearings is complicated, according to the repairers. The entire washing machine must be dismantled, including the removal of the drum and tub, to be able to separate the bearings. The dismantling process represents a disproportionate amount of the ease of disassembly steps and time. Repairers' opinions differ regarding the ease of disassembly of pumps and doors. The repairman who rated the disassembly of doors as complex mentioned that specific skills are required to remove a door seal. Parts that relatively often fail but are easy to disassemble are electronics, the pump filter, inlet valves, shock absorbers, and detergent system (e.g., the soap tray). According to the two repairers, the ease of disassembly for foreign objects strongly depends on their specific location in the washing machine.

Failure modes	Obbink	RTV Stegeman	Expert
1. Bearings	1		1
2. Electronics	4	4	4
3. Door	4	5	2
4. Pump	5	2	3
5. Pump filter	5		
6. Inlet valves			4
7. Heating element			5
8. Shock absorbers		4	
9. Foreign objects	3	5	
10. Switches		3	
11. Detergent system		4	

Table 2-9: Ease of disassembly of frequent spare parts failure modes (1 = very difficult, 2 = difficult, 3 = not difficult, not easy, 4 = easy, 5 = very easy)

2.3.8 Repairability time

Three repairmen were asked for the selected critical failure modes in **Table 2-4** to estimate the required time to repair these parts (see **Table 2-10**).

	Estimated repairability time (in minutes)		
	Obbink	RTV Stegeman	Expert
1. Bearings	120-150		120-180
2. Electronics	45 (control system)	30	30
3. Door	45 (cuff)	15	45 (cuff)
4. Pump	30	35	45
5. Pump filter	20		
6. Inlet valves			15
7. Heating element			25
8. Shock absorbers		40	
9. Foreign objects	30-45	15	
10. Switches		25	
11. Detergent system		30	

Table 2-10: Estimated average repairability time of frequent failure modes

Table 2-10 shows that the repairability time of defective bearings is high. Respondent three indicated that the repair time of the bearings can vary significantly per brand according to ease of disassembly. The repair time for bearings in a Miele washing machine is 180 minutes. According to the respondent, the same is approximately 120 minutes for an AEG or Bosch washing machine. The repair time for door failure modes depends on which part of the door needs to be fixed. According to respondents one and three, the repair time for a collar is high at 45 minutes, but replacing a hinge or a door takes much less time, according to respondent 2. With an average of 20 minutes, the pump filter repair time is the lowest of all repairability times.

2.3.9 Repair expertise

The repairability of washing machines is also affected by repair expertise. The repairers were asked to estimate for their selected failure modes how much specific repair knowledge and experience is required to repair them (see **Table 2-11**).

Failure modes	Obbink	RTV Stegeman	Expert
1. Bearings	4		5
2. Electronics	5	4	4
3. Door	3 (cuff)	2	4 (cuff)
4. Pump	2	3	4
5. Pump filter	2		
6. Inlet valves			3
7. Heating element			3
8. Shock absorbers		1	
9. Foreign objects	2	1	
10. Switches		4	
11. Detergent system		1, 3	

Table 2-11: Estimated repair expertise of frequent spare parts failure modes (1 = not at all, 2 = to a very limited extent, 3 = some, 4 =much, 5 = very much)

Table 2-12 reveals that the required level of repair knowledge for failure of bearings and electronics is high. According to respondent one, electronics demand comprehensive knowledge, e.g., to open and operate the service menu of a control system and to run various test programs. Respondent two indicated that the required repair expertise for failure modes in the detergent system strongly depends on the type of soap dosing system. Washing machines with a soap drawer do not require a repair background while washing machines with a soap dispensing system require some repair expertise. The repair of bearings takes a long time because the washing machine has to be disassembled, requiring extensive repair expertise. The repairers estimated that the repair expertise required for shock absorbers, the removal of foreign objects, pump filter, and detergent system is limited.
Furthermore, all three repairmen noted that the nature of repair had changed significantly in the previous year due to digitization. Nowadays, a repairer first looks at the error codes that a washing machine indicates on a laptop (Miele) or in the machine (Bosch-AEG). Subsequently, they physically investigate the diagnostic failure modes and possible underlying causes based on the available information. Despite the digital technology in current washing machines, users still play a relevant role during the diagnosis because they can enrich the digitized diagnosis with additional information about the device, such as any sounds and smells it might produce. With older non-digital washing machines, a repairer performs only manual testing, and his tacit knowledge and senses play a crucial role in diagnosing and repairing faulty machines.

2.3.10 Availability of spare parts

According to Cordella et al. (2019) and (Bracquené et al., 2018), the reparability of EEE products strongly depends on the availability of spare parts. Manufacturers must provide parts for a specified period to repair defective washing machines. According to respondent three, parts for German washing machines are available for an average of 15 to 20 years. Respondent two indicated that Miele parts are available for at least 20 years, while Bosch and AEG parts are available for ten to fifteen years. According to him, parts for non-German washing machines, such as LG and Indesit, are available for between 5 and 10 years in practice. The three respondents indicated that the delivery time for washing machine parts is short and takes place within 1-2 days.

2.3.11 Availability and accessibility of product and repair information

The availability of product and repair information, such as repair manuals, circuit diagrams, and exploded views providing insight into the specifications of spare parts is another factor affecting the repairability of EEE products (Bracquené et al., 2018; Cordella et al., 2019). Respondents indicated that relevant information is available on the internet and at manufacturers and repair websites, such as iFixit.com. On the Miele website, which is only accessible to certified repairers, product and repair information are obtainable for a minimal fee. Spare parts service providers also give customers access to relevant product and repair information. The respondents explained that non-certified repairers do not have access to the usage information stored in a washing machine.

2.3.12 General repairability score

Finally, respondents summarized various repairability aspects of selected failure modes in a general repairability score. **Table 2-12** presents the general repairability scores of the three repairers.

Failure modes	Obbink	RTV Stegeman	Expert
1. Bearings	2		1
2. Electronics	3	2	3
3. Door	5 (cuff)	5	4 (cuff)
4. Pump	5	3	4
5. Pump filter	5		
6. Inlet valves			4
7. Heating element			4
8. Shock absorbers		4	
9. Foreign objects	4	5	
10. Switches		3	
11. Detergent system		3	

Table 2-12: General repairability score of respondents (1 = very difficult to repair, 2 = difficult to repair, 3 = moderately repairable, 4 = easily repairable, 5 = very easily repairable)

Table 2-12 reiterates that, as already established in previous sections, bearings are difficult to repair. According to the repairers, electronics have a poor to moderate repairability score. Failure modes with a high repairability score refer to the door, pump filter, inlet valves, heating element, shock absorbers, and foreign objects. The repairability of switches and the detergent system is moderate, according to respondent two. The general repairability score closely matches the findings of the study by Tecchio et al. (2019), indicating that electronics and bearings generally have a low repair rate. Doors, pump filters, pumps, and foreign objects, on the other hand, all have a high repair rate.

The respondents suggested that the technical repairability score is closely related to the economic feasibility of the repair. All respondents noted that the cost of parts and required repair influence repairability in a negative way. For example, the costs of electronic components are very high. According to the respondents, the product design of recent washing machines hampers repair. Mainly, plug-and-play principles require the complete replacement of parts.

2.4 Current system solutions

2.4.1 Research approach

Five organizations specialized in return evaluation of EEE products have been investigated. The aim was to obtain understanding of return evaluation processes, to inventorize existing solutions regarding lifetime extension assessment, and to identify system elements applicable to the information system architecture for a collection agent. **Table 2-13** presents the case studies and related research methodologies.

According to Yin (2009), a case study is a suitable research method if accurate, contextual, and in-depth knowledge is collected about a specific case. The five organizations were selected as case studies because of their expertise in return logistics and return evaluation. The return logistics and return evaluation of four organizations are supported by digital technologies and are intensely data-driven. The case studies allow a thorough understanding of a complex organizational phenomenon or processes within a real-world setting by identifying how and why particular phenomena or events occur (Yin, 2009). Identifying applicable solutions for the systems in this study requires an open approach in which the phenomenon of assessment of return goods is studied in their natural environment. The case studies aimed to describe the process of return evaluation and identify the critical factors that determine it. Due to the explorative nature of the case studies, the data collection nature is semi or unstructured. Each case study is based on interviews and observations during fieldwork visits. During each field visit, a representative of a case study organization went through the business process at the physical location step by step. Critical process steps have been identified concerning intake, product assessment, and subsequent process routes. After studying the reverse logistics and return evaluation processes, an open, unstructured, or semi-structured interview took place with a process expert. These interviews aimed to gain insight into the system strengths, system drivers, lessons learned, and relevant system functionalities applicable to the defined system artifacts in this EngD study.

Case study organisation	Core business	Organization type	Role respondent	Relevance	Research method	Number of visits
Return logistics center 1	Data-driven reverse logistics and repair of returned consumer electronics	Commercial	Operational manager reverse logistics	Understanding of data-driven return evaluation system of returned consumer electronics	Unstructured direct observation	2
Return logistics center 2	Data-driven reverse logistics and repair of returned consumer electronics	Commercial	Operational manager after sales services consumer electronica	Understanding of return evaluation and product repair system of returned consumer electronics	Semi-structured interview and unstructured direct observation	1
Mobility aids provider	Data-driven reverse logistics and repair of returned mechanical and electronic aids	Commercial	Logistic Engineer	Understanding of return evaluation and product repair system of returned aids	Semi-structured interview and unstructured direct observation	1
ICT services developer	Software solutions for thrift stores, planning and registration system of disposed consumer electronics	Commercial	Sales- & Account Manager	Demonstration of data-driven software application disposed consumer electronics	Demonstration	1
EEE collection agent	Collection and repair of discarded washing machines	Commercial	Operational manager collection point and repair facilities	Understanding of return evaluation and product repair system of returned consumer electronics	Open interview, unstructured direct observation	2

Table 2-13: Researched case studies return evaluation

2.4.2 Research findings

In **Appendix B** insights and lessons learned obtained from the descriptive case studies are outlined. The case studies show that commercial organizations, such as the return logistics centers and the mobility aids provider, have intelligent data-driven systems that have primarily automated the intake, assessment, and marketing process. System and process integration with relevant value chain actors, such as customers and suppliers, contribute as an operational excellence strategy to informed decision-making regarding reuse options. Economic principles play a significant role in this process. Product recovery of collected EEE products under the influence of narrow profit margins and high labor costs is economically difficult to achieve. The case studies indicate that the level of the initial product price strongly influences the chance of extending the lifetime. The two commercial return logistics centers sort out products with low residual economic value early in the process. Another factor that determines whether the five investigated organizations consider lifetime extension as an attractive circular strategy is related to the ownership of the product. The case study concerning the mobility aids provider reveals that the organization remains the product owner during the entire product usage cycle. Their pursuit of profit optimization relates positively to lifetime extension strategies. Such an aim encourages the

mobility aids provider to make decisions at the component and product level from an economic and ecological perspective. Because most washing machines in the Netherlands are owned by a household and not by the manufacturer, the latter has virtually no incentives to use the residual value of an appliance. Manufacturers prefer to sell new washing machines because this leads to higher profit margins.
Furthermore, all five case studies demonstrate that business processes are highly standardized due to operational excellence value strategies. Such standardization is reflected in the data governance policies (data quality and interoperability) they implement towards value chain partners and the prescriptive procedures and protocols for employees. Task standardization favors employees with limited technical expertise. The case studies reveal that such employees can perform simple standardized return evaluation tasks.

The case studies related to the ICT services developer, mobility aids provider, and the two return logistics providers reveal that the digital systems are not exclusively aimed at return evaluation but rather integrate different aspects of the value chain. Such as a customer's registration of an EEE product, route planning, reception, warehousing, fulfillment, and sales. System integration contributes to full transparency of the value chain and stimulates collaboration in the value chain. The organizations' processes generate various information used in contact with customers. For example, the product sheet that the ICT services developer creates for each reusable EEE product provides customers insight into product information, test results, and repair work, which favorably contributes to their confidence in the technical quality of an electrical device.

The case study of an EEE collection agent clarifies that a collection and return evaluation system for discarded white goods can be realized without supporting digital technologies. Simple visual and basic technical checks select promising washing machines for lifetime extension. Relatively high repair rates are possible because parts are harvested from German brands and implanted in reusable washing machines. The limitation of the EEE collection agents’ return evaluation system is that modern washing machines with digital technologies cannot be accessed. Manufacturers are hesitating to provide organizations access to support tools. Furthermore, large volumes of supplied EEE products are required for all cases to make the system economically viable. Well-organized return logistics operations are a critical precondition for return evaluation.

The case studies are valuable input for the system development of the lifetime extension information system for collection agents. Standardization of the input, throughput, and output of the assessment processes is crucial to make the return evaluation of washing machines viable. Significant application possibilities of system elements in the case studies can be traced back to product identification and the systematic, unambiguous, and basic method of product assessment by experts based on critical parameters. An important lesson learned is that the case studies from an appreciative perspective maximize the residual value still implicit in the process by conducting objectified assessments. Therefore, as part of a decision support system (DSS), a lifetime extension assessment component needs to be developed, enabling standardized, informed decisions about the feasibility of extending the lifetime of washing machines. Another promising application concerns the digital software applications that prescriptively steers employees with a limited technical background through a standardized operational assessment protocol on a smartphone or tablet.

It is critical to develop the system architecture for collection agents from a circular ecosystem perspective because the required assessment data depends on the data provision of multiple external stakeholders in the washing machine ecosystem of collection agents. In addition to the basic assessment criteria, the preconditions are crucial for the success of the system architecture for collection agents, such as the availability and quality of data and efficient return logistics. Another consideration concerns the harvesting of parts from defective washing machines. Although the harvesting of parts is not part of the system, utilizing their residual technical and economic value is an important critical success factor.

2.5 Summary and conclusion

This chapter has provided insight into the current washing machine ecosystem in which collection agents operate. The ecosystem mainly focuses on materials recycling. Transaction-driven business models, economic incentives that pressure the feasibility of high-quality circular strategies such as reuse and repair, product design strategies, and poor information sharing between stakeholders in the washing machine ecosystem discourage the extension of the lifetime of washing machines in the current status quo. Collection agents' collection services focus on receiving, sorting, registering, administering, invoicing, and distributing discarded electronic products.

The literature review contributed to identifying the factors that influence the lifetime extension of washing machines and are relevant for the development of the lifetime extension assessment component. The literature review results indicate that, at a product level, construction, design, durability, and repairability greatly affect the technical lifetime extension of washing machines. The literature review also clarified that lifetime extension depends on developments in the washing machine market and ecological impact. Digital technologies and the proposed obligation for DPPs can support data-driven lifetime extension assessment of collected washing machines by collection agents in the future.

Interviews with repairers confirmed that the repairability of washing machines highly affects the lifetime extension of collected washing machines. The diagnosis time for failure modes, accessibility, ease of disassembly, repair time, repair expertise, and availability of spare parts and repair information also influence the repairability of washing machines. The interviews with repairers made it clear that the repairability of critical washing machine parts, such as bearings and electronics, is not economically feasible. On the other hand, the repairability level of parts such as the pump, pump filter, and shock absorbers is high. Furthermore, German washing machine brands appear easier to repair than non-German brands.

The analyses of operational system solutions reveal that information and data availability and digital and process system integration is crucial to professionalize return assessment operations.

3 Future washing machine ecosystem

The transition to a circular economy and other external developments might affect both how stakeholders in the future washing machine ecosystem act and the lifetime extension assessment of electronic products. This chapter presents a vision of how a future washing machine ecosystem might evolve. **Section 3.1** elaborates on two socio-technical scenarios and their possible consequences for lifetime extension assessment of washing machines. **Section 3.2** presents the literature review findings on the characteristics of a circular ecosystem. A value network is modelled from the perspective of a circular ecosystem in which the stakeholders interdependently realize a collective value proposition. **Section 3.3** summarizes and concludes the chapter.

3.1 Socio-technical scenarios

The ambition to extend the lifetime of collected washing machines on a large scale is highly dependent on various trends and developments in the washing machine sector. The environment of the washing machine ecosystem is dynamic and uncertain and influences its operation. The intended role of collection agencies in a circular ecosystem, in which information sharing and collective circular value propositions are essential, influences how washing machines are assessed for lifetime extension. This section describes how the washing machine ecosystem might develop by elaborating on a socio-technical scenario. The scenario maps out the forces which act on the washing machine sector and the consequences this can have for the lifetime extension assessment. The time horizon of the scenario was set for 2030, which coincides with the year that the Dutch government has committed to halving the country’s raw material consumption as part of its circular economy policy.

3.1.1 Socio-technical scenario development process

Socio-technical scenarios help explain transitions at the level of societal functions fulfilled by socio-technical systems (Geels, 2005). According to Geels, such socio-technical systems consist of aligned elements like technology, knowledge, user practices, market regulations, cultural meaning, and supply networks. An analysis of a socio-technical system helps to understand the forces acting on the transition of a socio-technical system from a previous equilibrium point (de-alignment) to a new equilibrium point (re-alignment): *“Socio-technical systems are created, (re)produced and redefined by several actively social groups, for instance, firms, universities and knowledge institutions, public authorities, public interest groups and users”* (Geels, 2005, p. 446).

Each social group (or stakeholder) has its own frame of reference, including interests, perception of problems, values, strategies, resources, and preferences. Explorations of expected transition pathways are beneficial to be able to gain in-depth insight into a system and its related societal stakeholder dynamics at the multiple levels of 'landscape developments,' 'socio-technical regimes,' and 'technological niches.' The system dynamics affect stakeholders' behaviors through changing (societal) functionalities (e.g., changing legislation or consumer preferences). As a method, the socio-technical scenario elaborated here provides valuable tools to explore an intended system innovation and its accordant transition pathways (Hofman & Elzen, 2010). In this study, a socio-technical scenario elaboration offers valuable insights into the expected future socio-technical regime in the washing machine sector. A desired structural adoption or lifetime assessment of discarded washing machines in a washing machine ecosystem depends on the characteristics of the socio-technical regime in 2030. In the treatment design phase, the socio-technical scenarios will motivate design principles and choices in the lifetime extension information system for collection agents, and the relevant assessment component.

During the scenario development process, several steps were performed. After a theoretical literature review on socio-technical scenario development, an explorative work session was held with the client to discuss critical factors that might be game changers for the current socio-technical regime of the washing machine sector. These factors can be traced back to trends in society, the market and business, technology, the role of governments, and the macro environment. Following this, a ninety-minute brainstorming session was held with CirkelWaarde participants and student researchers with various study backgrounds from Saxion University of Applied Sciences. As input for the socio-technical scenarios to be formulated, the brainstorming session aimed to identify relevant trends and developments that might influence the state of the washing machine sector in 2030. The results of this brainstorming session are outlined in **Appendix C**.

In addition to the brainstorming session, literature and document research was conducted into technological innovation, product design, data governance, governance, business model innovation, consumer behaviors, and EEE value chains. These factors were determined during additional consultation with the client. Based on the results of the brainstorming session and the insights gained from the literature study, two socio-technical scenarios were formulated during a working session with the client. The scenarios are formulated based on seven factors identified from the literature and document research (see **Table 3-1**). In scenario 1, a configuration is assumed in which washing machine manufacturers control the access of product and usage data and are reluctant to share this data with other stakeholders, such as customers and collection agents. Scenario 2 assumes a scenario in which various washing machine ecosystem stakeholders, such as the users of digital washing machines and collection agents, have access to product and usage data according to their information needs. The influence of data-driven digital washing machines and the consequences for business models, sales markets, the washing machine ecosystem, collection services, and consumer behaviors are significant. Therefore, data accessibility is the leading discriminating factor in the two scenarios. Lifetime extension assessment requires the accessibility of product and historical usage data.

Scenario development factors	Explanation	Scenario 1: Washing machine manufacturers control access to product and usage data	Scenario 2: Washing machines users have access to product and usage data
1. Technological innovation	Digital technologies are enablers of a circular economy and potentially extend product lifetimes (Aldea et al., 2018; Berger et al., 2022; Ertz et al., 2022a; Nham, 2022; Peeters et al., 2021; Ranta et al., 2021; Saarikko et al., 2017).	On the product level, continuous technological and digital innovation of washing machines already occurs. The benefits of digital technologies, such as Internet-of-Things applications and data analytics, are utilized in favor of manufacturers alone.	Benefits of digital technologies are utilized in favor of all EEE value actors involved. Digital business ecosystems manage interconnected information technology resources and drive innovation in the washing machine industry. Introduction of DPPs allow data sharing during the product lifecycle of washing machines across EEE value chain.
2. Product design	Product design strategies influence the product lifetime and recoverability of EEE, e.g., design to last long or design for repairability (Bocken et al., 2016; Den Hollander et al., 2017; Moreno et al., 2016).	Product design strategies gradually favor long life and lifetime extension of washing machines to optimize one single product lifecycle.	Circular product design strategies generally favor lifetime extension, serviceability and reuse of washing machines, components and materials in multiple life cycles.
3. Data governance	Under the influence of the transition to a digital circular economy and an increasing flow of information and data between value chain actors, understanding how data governance is implemented is necessary to provide clarity about data ownership, quality, accessibility, and security (Abraham et al., 2019; Plotkin, 2020; Spanaki et al., 2022).	Producers of washing machines own the data. Users have limited ownership and access to product and usage data generated by their own washing machine. Limited manufacturers' system interoperability due to lack of standardization of data formats, and poor data quality hamper availability and accessibility of product and historical data for collection points.	Users of washing machines own the data and have access to product and usage data generated by their own washing machine. Full system interoperability among EEE value chain actors due to EEE sector wide agreements on interoperability issues. Full data availability and accessibility of product and historical data for collection points.
4. Governance	Governmental policies and regulations are key enablers in the transition to a circular economy at the macro, meso and micro level (Cramer, 2022; Palm & Bocken, 2021; Velenturf et al., 2018; Wasserbaur et al., 2022).	Governments define circular economy policies and facilitate circular initiatives.	Governments define circular economy policies and actively enforce them through the use of mandatory laws and regulations.
5. Business model innovation	In the transition to a circular economy the adoption of circular business models in the washing machine industry contributes to product lifetime extension and drives the EEE value chain (Bocken & Ritala, 2021; Bressanelli et al., 2017; Ertz et al., 2019; Geissdoerfer et al., 2020; Pieroni et al., 2021).	Sales-oriented business models stimulate high sales volumes and ownership of washing machines. Product as a Service Business models are introduced into B2B markets.	From the perspective of a functional economy, Product as a Service Business Models drive usage of washing machines.
6. Behaviors of citizens and customers	The attitudes, cognitions, and behaviors of consumers and citizens influence their willingness to participate in a circular economy and to deal with electronic products in a circular manner (Elzinga et al., 2020; Gomes et al., 2022; Gülserliler et al., 2022; Huttunen et al., 2022; Jaeger-Erben et al., 2021; Sari et al., 2021).	In general, citizens and customers have limited environmental awareness and willingness to actively participate in a circular economy and product lifetime initiatives.	Citizens and customers are active participants in the transition to a circular economy and claim their consumer rights. Citizens and customers adopt an eco-friendly lifestyle wherein product lifetime extension is commonplace.
7. Value chain	The transition to a circular economy in which control and monitoring of a washing machine in its product life cycle are key requires a systemic and holistic perspective on the E-waste value chain and collaboration between the value chain actors (Aminoff & Sundqvist-Andberg, 2021; Bressanelli, Saccani, Pigosso, et al., 2020; Islam & Huda, 2018; Rizos & Bryhn, 2022).	Collaboration among actors in the EEE value chain is suboptimal. Manufacturers dominate the sales markets and value chain management. Limited formal collection of disposed washing machines.	Systemic and integrative EEE value chains favor the transition to a circular economy and collaboration among value chain actors. The collection service is integrated into the product lifecycle and the EEE value chain.

Table 3-1: Scenario factors

3.1.2 Scenario 1: washing machine manufacturers control data accessibility

In 2030 a growing group of consumers is registering washing machines in the manufacturer's cloud. The use of digital technologies such as the Internet of Things gives manufacturers extensive insight into the usage and maintenance information of users' washing machines and supports them in marketing and product development activities, as well as driving new business service concepts such as smart maintenance. Under the influence of the increased flow of connected digital washing machines, big data analytics is becoming increasingly important for manufacturers. Producers perform such data analytics in-house. Users see limited functional information about their washing machine on their smartphones and can set it according to their wishes. At the same time, the information that producers make available creates long-term lock-in effects for users. The production of washing machines and data ownership ensure that the manufacturer is the focal supply chain company in the consumer electronics chain and enables them to dictate the rules of the game in the chain. Each producer imposes restrictions and sub-optimizes its product and data exchange within its framework.

At the product level, the manufacturers are at the forefront of technological product innovations. However, they mainly develop such innovations in-house and fiercely protect them with patents. It is true that in the Eco-design directive and the use of repair and durability indices, governments are steering towards better circular product design that facilitates lifetime extension, while the 'right to repair' action movement and consumers are increasingly claiming their rights to durable and repairable EEE. Still, manufacturers anticipate a reactive attitude to such European regulations and ensure that they meet the minimum requirements set by governments. Although producers respect the European Data Governance Act, information sharing across the washing machine ecosystem is still limited. Such reactivity on the part of producers is reinforced by the fact that governments, under the influence of Extended Producer Responsibility, have started to require producers to maintain ownership of the washing machine throughout its entire product life cycle. Consequently, third parties who can theoretically add meaningful product and service-oriented innovations are excluded by washing machine manufacturers.

Despite the opportunities the digital revolution offers manufacturers' information systems are wary of sharing competitively sensitive information with third parties. They are, therefore, mainly interoperable and compatible only with other value chain actors in the forward supply chain. Information sharing in the reverse supply chain, on the other hand, is limited. Dissatisfied with the paucity of information sharing, washing machine consumers hack and purchase affordable bypass devices from hardware stores that help read the usage data from their washing machine. Based on reputation considerations, small-scale manufacturers, in collaboration with third parties, are initiating take-back initiatives to extend the lifetime of reusable washing machines. Material reuse, on the other hand, dominates as a circular strategy. In the washing machine ecosystem, there is a trend that under the influence of data-driven product-as-a-service business models, producer strategic partnerships are entered into with certified retailers and service providers to provide additional services. Such product-as-a-service business models give manufacturers and retailers incentives to actively focus on extending the lifetime of washing machines by applying design strategies such as design for reliability, upgradeability, and compatibility and, together with strategic partners, developing collection services for this specific product group. At the same time, sales-oriented business models are still dominant in the EEE sector, and manufacturers struggle to release themselves from their linear economy paradigm and vested interests. In response to this defensive attitude, a new EEE producer has entered the EEE market as a niche player, focusing on the eco-friendly market segment. The niche player supplies washing machines with robust product quality that last long, have a high degree of standardization, are repairable, have open-source technology, and allocate data accessibility to the owner.

3.1.3 Scenario 2: washing machines users have access to data

Affected by the enormous flow of digital washing machines onto the market and a revolution in innovative digital technologies, washing machine ecosystem stakeholders are united in an overarching democratic digital ecosystem. These digital ecosystems consist of a wide variety of existing and new actors acting according to their unique specialization in the product life cycle of a washing machine. These actors include connected washing machines, suppliers, manufacturers, users, third-party repair services, collection service providers, third-party data service providers, network operators, retailers, support service centers, marketing and social media service providers, product designers, and all their respective technologies. Within the washing machine ecosystem, uniform data governance policies contribute to the interoperability of the systems of the various partners. All washing machine ecosystem stakeholders benefit from information sharing, taking into account General Data Protection Regulation (GDPR) issues. European governmental data laws and regulations oblige manufacturers to share a substantial amount of product and usage data with users and other washing machine ecosystem stakeholders. Data sharing propagates product and service innovations in the EEE sector. The transparency of the EEE product life cycle and the extent to which products are sustainable and circular also show positive indicators. As part of the EU Green Deal, the mandatory introduction of DPPs as information carriers has ensured that a washing machine product is traceable throughout its entire product life cycle.

Data in a DPP stimulate smart maintenance in washing machine users and support collection and repair service providers in their informed decision-making to prolong the lifetime of a washing machine. Under the influence of mandatory circular economy government regulations and product-as-a-service business models facilitated by digital business ecosystems, manufacturers produce washing machines according to digital circular product design strategies. The producers have specialized extensively in EEE technological product innovation. Influenced by the rich supply of information on the circular economy and their EEE devices, effective circular economy government policy, and a pressing shortage of energy and raw materials, consumers and citizens have increasingly developed into conscious citizens. Circular values drive their attitudes and buying behaviors, driving market demand for reusable EEE and product lifetime services. Owning things is becoming less important to more and more consumers and is making way for a sharing and functional economy.

3.1.4 Scenario consequences

These scenarios clarify that the effectiveness of collection services aiming for product lifetime extension strongly depends on the characteristics of the socio-technical regime in which they operate. Overarching landscape developments such as climate change, resource depletion, geopolitics, EU Green Deal policies, and increasing environmental pollution severely test the current socio-technical regime of the washing machine and WEEE industry. Digital washing machines driven by Industry 4.0 applications, DPPs, circular product design, and artificial intelligence technologies as technological niche innovations, strengthened by the aforementioned pressing landscape developments, are potential disruptors of the current socio-technical regime.

Figure 3-1 models macro-level landscape developments and the technological niche innovations that affect the socio-technical regime of the washing machine sector. The two scenarios in the previous sections have elaborated on how this happens. Several critical game changers challenge the current socio-technical regime and determine the transition pathway to an envisioned regime that is based on circular economy principles. Data availability and accessibility for various washing machine stakeholders enable product lifetime initiatives during a washing machine's several product lifecycle stages. The introduction of DPPs and the European Data Governance Act force the desired data availability and accessibility. The rise of circular ecosystems, in which current and new EEE actors unite to deliver a circular value proposition collectively, is radically changing the washing machine sector. Information sharing is commonplace here. Digital technologies and DPPs enable information sharing and offer new application possibilities. From a product lifecycle perspective, data-driven, circular business models are increasingly based on product-service systems.

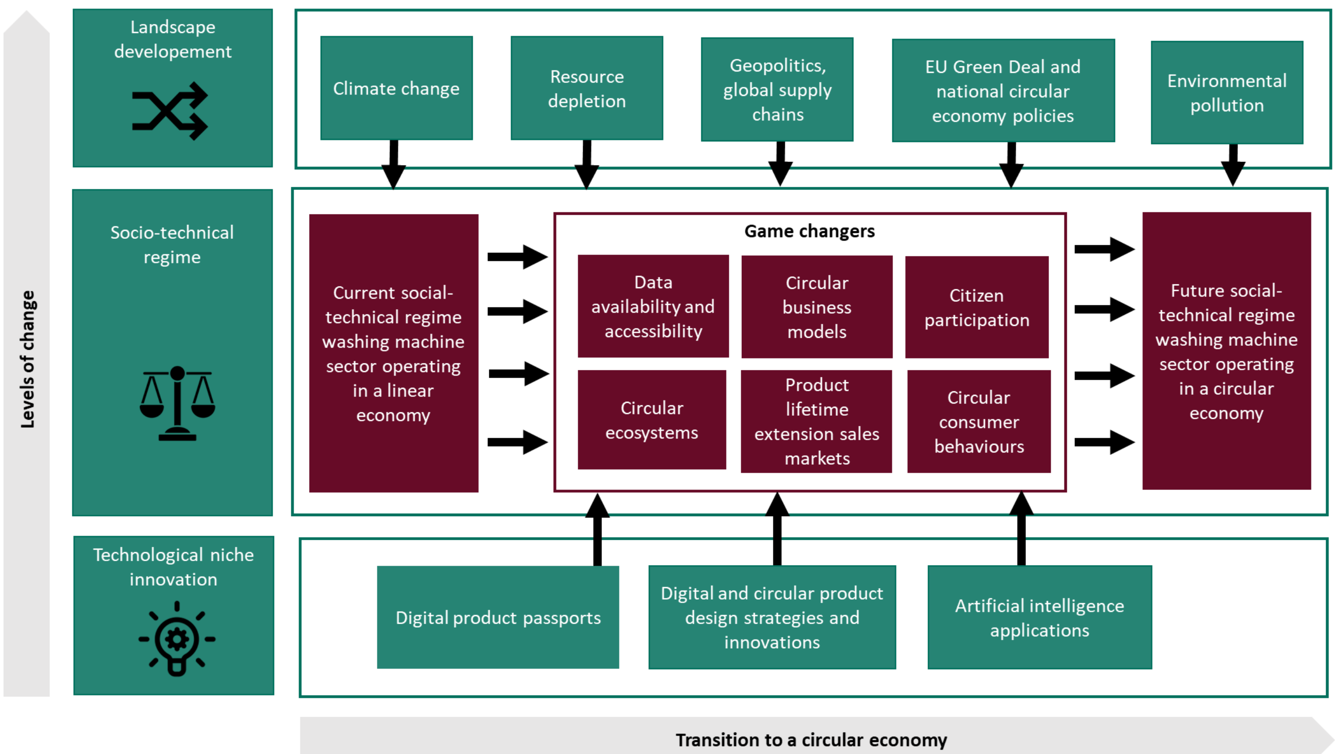


Figure 3-1: De-alignment and re-alignment transition pathway for washing machine sector

A booster of lifetime extension concerns the market demand for second-hand products. Consumer behaviors can explain this growth and the associated attitudes of increasing eco-friendliness. Reusable washing machines have become an attractive alternative for a growing group of consumers. A growing group of citizens is actively participating in the transition to a circular economy. This is reflected in the correct delivery of discarded electronics to collection agents. The interplay of these factors causes gradual de-alignment and tensions in the current linearly oriented, socio-technical regime of the washing machine sector. Depending on the extent to which governments actively and forcefully direct their circular policies and regulations towards the aim of product lifetime extension initiatives, and the extent to which technological innovations continue, a new socio-technical regime may well eventually emerge in the washing machine ecosystem that is based on circular economy principles.

3.2 Circular ecosystem and value network

3.2.1 Literature study results

The transition to a circular economy is expected to generate a large market for second-hand washing machines. In the introduction of this report, the expected business opportunities of second-hand washing machines are addressed. In the socio-technical scenarios elaborated herein, growing product lifetime extension sales markets, business models, and data availability are essential game changers in the transition to a circular economy that focuses on extending lifetime. Circularity is a problem that the stakeholders in the washing machine ecosystem cannot solve alone. The current ecosystem is characterized by the opportunistic behavior of actors that blocks a systemic and holistic view of lifetime extension. The transition to a circular economy requires an ecosystem innovation based on circular principles that address circular strategies (Konietzko et al., 2020). Collaboration between different actors in a washing machine ecosystem is necessary to develop a joint circular value proposition from a product life cycle perspective grafted onto lifetime extension. This calls for the introduction of circular ecosystems. Trevisan et al. (2022, p. 292) state that a circular ecosystem is “a co-evolving, dynamic and potentially self-organizing configuration, in which actors integrate resources and co-create circular value flows in interaction with each other.” The circular ecosystem concept aligns with the principles of a circular economy: systemic thinking, innovation, stewardship, collaboration, value optimization, and transparency (Bertassini et al., 2021). Ecosystem actors achieve joint circular strategies and goals because their activities are jointly coordinated; they act interdependently and carry them out jointly (Konietzko et al., 2020). Digital technologies and data play a crucial role in circular ecosystems incorporating circularity principles (Voulgaridis et al., 2022). Data integration and sharing support informed decision-making and value-creation in the circular ecosystem (Trevisan et al., 2022). Governance mechanisms structure the coordination, collaboration, information sharing, and value sharing amongst circular ecosystem actors.

Information systems for collection agents and the assessment component can contribute to the transformative innovation of the current washing machine ecosystem toward a circular ecosystem. The collection agents’ information system can potentially support future circular ecosystems in their collective value proposition to extend the lifetime of electronic products. The technological innovations outlined in the scenarios, such as digital technologies in washing machines and DPPs, can disrupt the current socio-technical regime of the washing machine sector. Realization of the second socio-technical scenario, where washing machine owners control the data, implies that the stakeholders in the circular washing machine ecosystem have active collaborative relationships with each other to add circular value at the level of the circular ecosystem in which they operate (Bertassini et al., 2021). Such innovation is reflected in changing roles and value exchanges between the actors in a circular ecosystem that stimulates the application of “slow the loop strategies” (reuse, repair, refurbishment) in the mid-stage of a product lifecycle.

From a design perspective, the question is how the transition to a fully-fledged circular ecosystem that strives to extend the lifetime of electronic products can be realized. As the problem investigation has clarified, the residual value of collected washing machines is insufficiently utilized in the current situation. Trevisan et al. (2022) position the value element at the center of their circular ecosystem conceptual framework. Value is "the quality (worth) of something (tangible or intangible) as perceived by a stakeholder concerning their goals/needs" (Aldea et al., 2015). From an ontological viewpoint, value ascription can be modeled as "a judgment relationship between an agent (the value beholder) and a value bearer that the beholder judges as having value for someone (the value beneficiary)" (Sales, 2019, p. 29). The value bearer is a value experience or a value object. The type of value that Trevisan et al. (2022) define relates to the use value which satisfies a requirement, want, or need. For example, a customer's need for a second-hand washing machine.

The interdependence between circular ecosystem actors under the influence of complementary relationships is decisive in joint circular value creation for customers. Thus, the value concept plays a central role in the circular ecosystem framework and is related to circular value proposition, value co-creation, collective value capture, and multiple circles of value (see **Figure 3-2**). The output of a circular ecosystem is a circular value proposition, in this case, the lifetime extension of washing machines.

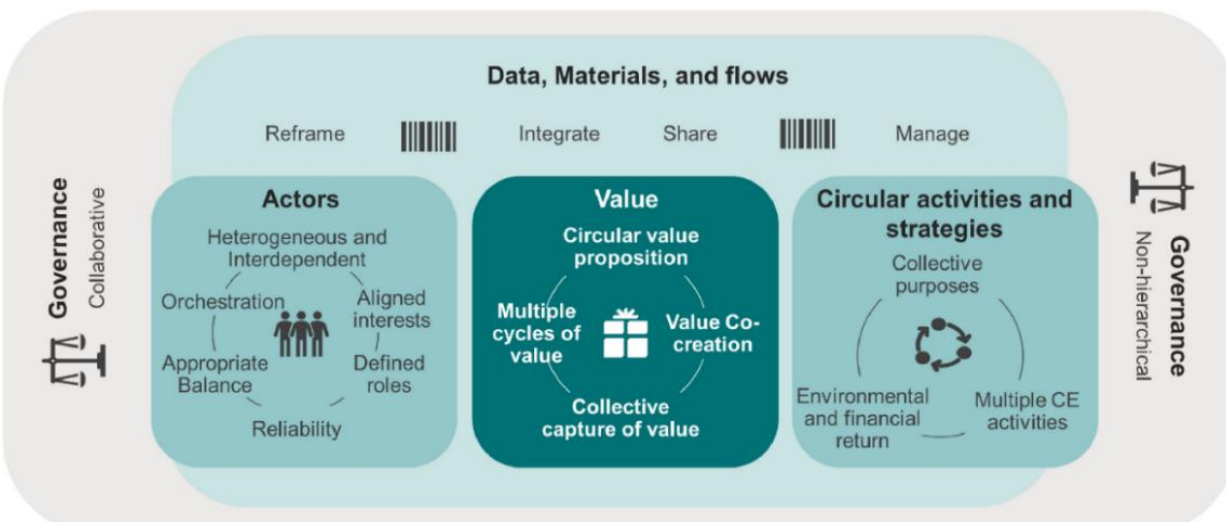


Figure 3-2: Circular ecosystem conceptual framework (Trevisan et al., 2022, p. 293)

In addition to use value, it is essential from a circular ecosystem perspective to investigate whether the interdependencies between the ecosystem actors are economically attractive to them. The value exchanges between the actors determine this attractiveness. From a system perspective, the value network concept can be used to clarify the interdependencies between actors in a circular ecosystem aiming to satisfy customers' needs by offering a collective value proposition. A value network is a collection of independent actors offering value to a market by engaging in economic exchanges (Gordijn & Wieringa, 2021). Each actor adds value activities to the value network. Value objects, such as money or non-money objects, are exchanged in a value transfer between actors in the value network. In a value network, one or more value interfaces occur between actors and their value activities to perform a service to an external customer as a collective value network that aims to meet customer's needs. The actors in the value network depend on each other, enabling such a collective value proposition. The attractiveness of value exchanges between providers and requesters contributes to the viability of the value network, mainly driven by their willingness to transfer a value object (Gordijn & Wieringa, 2021). If an optional value exchange between actors is not attractive to one of the actors, it will not occur.

In this study, three value models of the washing machine ecosystem have been modeled in the software application *E3 value* to explain how the value exchanges in a network contribute to the enhanced lifetime extension of collected washing machines. *E3 value* is a conceptual modeling language and set of analysis techniques to represent and analyze value networks (Gordijn, 2004). The value model is a representation of a value network in *E3 value*. In this study, a model-based value model explores how the value exchanges between actors, driven by customers' needs for second-hand washing machines, might benefit the ecosystem. A limitation of this elaboration is that the *E3 value* language only focuses on economic value: use value might also be relevant for inclusion in the value model. Therefore, the assumption is that the *E3 value* model is also suitable for expressing use values.

The first elaborated value model represents the value network of the current washing machine ecosystem. Representing the current situation as a baseline is relevant to providing insight into how such a value network can evolve under the influence of circular principles that stimulate lifetime extension. The second elaborated value model, affected by the elaborated socio-technical scenarios outlined in **Section 3.1**, represents a future value network that aims to extend the lifetime of electronic products.

3.2.2 Towards a future value model

Figure 3-3 and Figure 3.4 represent a value model of the current washing machine ecosystem. In fact, *E3 value* models two market scenarios in the value model. The first scenario involves selling a washing machine. The second scenario concerns the collection of materials from discarded washing machines. Each scenario has a different time frame.

Figure 3-3 shows the value model where a customer's need to purchase a washing machine triggers the value network. The value network clarifies that the customer need for a (mostly new) washing machine generates a dependency path between retailers, importers, manufacturers, and virgin material and component suppliers. The mutual economic and product-related value exchanges encourage for these actors to participate in the value network.

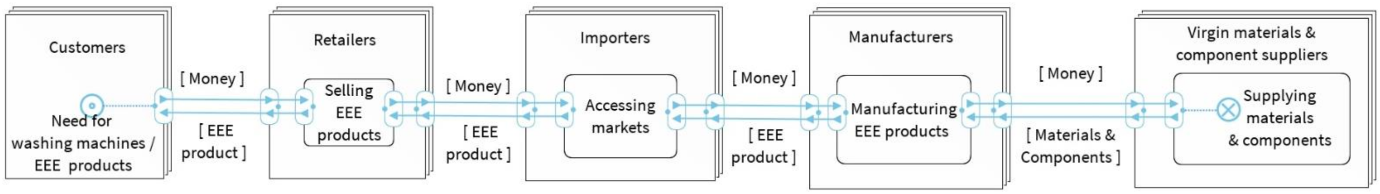


Figure 3-3: Current value exchanges triggered by customer needs for washing machines

Figure 3-4 presents a value model where the need for second-hand materials suppliers triggers an interdependency path of value activities and economic value transactions between suppliers, recyclers, collection agents, and customers. The dependency path ends with a customer discarding a used washing machine. The value model reveals that the economic value exchanges between the actors mentioned encourage them to participate in the value network. These value exchanges are attractive for the value network actors for materials from EEE products, but not on a product and component level. Thus, the current washing machine ecosystem does not stimulate economically attractive value exchanges between value network actors concerning the reuse of EEE products and components. Consequently, such potential value exchanges are not part of the value model. The role of a collection agent in the current ecosystem can be traced back to the principles of operating in a linear system. The stakeholders in the washing machine ecosystem examine solutions to address circular economy challenges from a linear economy perspective. As a result, the highest achievable circular strategy is currently materials recycling.

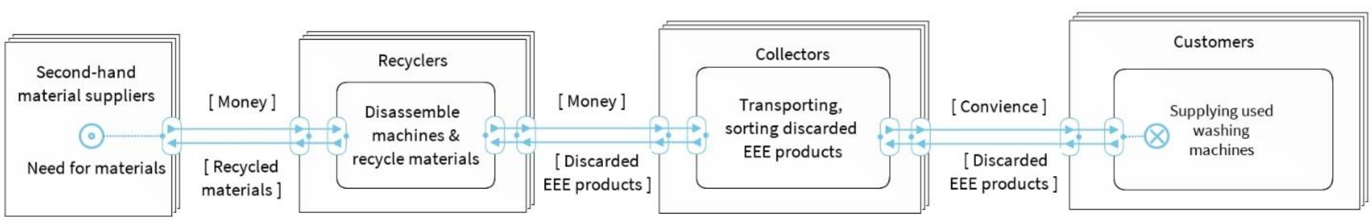


Figure 3-4: Current value exchanges triggered by second-hand material suppliers needs for used washing machines

Within the present circumstances, possible product lifetime extension business models and related value exchanges are not profitable for the stakeholders of the washing machine ecosystem. Compliance from governments and new value network actors, such as repair service providers, is required to mobilize a value network which strives for higher circular strategies. The interviews with repairers indicated that extending the lifetime of washing machines is often not feasible. Repairers indicate that high wages and spare parts costs usually do not outweigh the initial list price of a washing machine. Consumerism influenced by a throwaway society causes consumers to purchase affordable washing machines. The product quality and design of these affordable washers discourage repair. Such product properties encourage most consumers to purchase a new washing machine instead of repairing a defective washing machine. Looking at this problem from a value perspective, it becomes clear that economic values are decisive in determining whether lifetime extension is feasible. This economic value mainly depends on the initial product list price, new washing machine parts costs, and labor costs. A one-off economic transaction drives the underlying business models of repairers for a product or service between two actors, such as between a repairer and a consumer. However, as abovementioned, high cost of parts and labor discourages lifetime extension. Therefore, the possible value exchange is not attractive to stakeholders in the current washing machine ecosystem.

3.2.3 Future value model

The socio-technical scenarios elaborated above have provided insight into the forces acting on the washing machine sector and the consequences this may have for how the socio-technical regime will develop in the coming years. This section presents a value model for the near future that represents a value network aiming for the lifetime extension of collected washing machines. The elaborated value model aims to provide insight into which value activities actors add to a value network and which value exchanges they exchange with each other with the intention of realizing a collective value proposition as a circular ecosystem. Collection agents are part of this value model.

During the design of a future value model, several assumptions were made. These assumptions are based on government policy documents pursuing a transition to a circular economy, such as the Dutch government's "National Circular Economy Program 2023 – 2030" which explicitly addresses lifetime extension. In line with the detailed scenario, circular business models, growing second-hand markets, and information sharing are essential building blocks. More specifically, the following assumptions underlie the near-future value model:

- Value network actors participate interdependently in a circular ecosystem where information sharing is commonplace during the whole product life cycle.
- The growth in market size of eco-friendly customers increases demand for second-hand washing machines.
- Collectors pursue large-scale product lifetime extension strategies affected by compliance and producers' willingness to participate in a circular economy.
- As part of an information system for collection agents, a lifetime extension assessment component professionalizes collection agents' assessment capabilities. An assessment of collected washing machines clarifies whether lifetime extension is feasible and guides the selection of an appropriate circular strategy for a discarded EEE product to follow (e.g., reuse, repair, or refurbishment).
- Besides collecting discarded EEE products, collectors will harvest the parts of end-of-life EEE products.
- Producers provide EEE product information to collectors for lifetime extension assessment purposes. Products provide EEE product information to lifetime extension facilities to enable product recovery.
- Lifetime extension facilities refurbish, repair, and upgrade washing machines that can be reused. They use harvested parts to repair faulty washing machines.

- Under the auspices of a take-back system, discarders receive a financial incentive from a collector to improve the quality and quantity of delivery of EEE products.
- Affected by the influence of the scarcity of raw material and (inter)national circular economy policies, the demand from material suppliers for recycled materials increases. However, this is not directly reflected in the increased manufacturers' demand for recycled materials.

Figure 3-5 represents the future model. Four customer needs are distinguished in the value model:
- Consumers want to purchase washing machines for laundry purposes.
- Materials suppliers want to purchase used materials and spare parts.
- Repair facilities need repair information to facilitate repair processes.
- Collection agents need washing machine product and usage information for lifetime extension assessment purposes.

The customer needs generate value exchanges among actors in the value network to deliver a value proposition. The need for second-hand washing machines triggers interdependency paths among customers – retailers – repair facilities – collection agents – discarders. Financial–product transactions drive the value exchanges between actors in this interdependency path. Retailers are assumed to include second-hand washing machines in their range to a large extent. Repair facilities repair “end-of-use” washing machines that qualify for the next use phase. To fulfill its role as a repair facility, there must be a value exchange with a spare part provider to purchase new spare parts and a value exchange with a recycler to purchase harvested spare parts from washing machines. The relevance of recyclers harvesting parts from collected washing machines becomes more evident in the context of a circular economy and generates value exchanges with repair facilities. In addition to collection, the value activities of collections agents are aimed at the lifetime extension of collected washing machines. Discarders of washing machines, mainly citizens, are rewarded with a financial incentive in the value model. This incentive encourages them to hand in a used washing machine to a collection agent via extensive formal collection channels.

The elaborated value model assumes that the modelled value exchanges contribute to the economic feasibility of lifetime extension. As a critical success factor in the value model, financial incentives, influenced by a significantly increased market demand for second-hand washing machines, stimulate collection agents to extend the lifetime of washing machines instead of materials recycling.

Furthermore, the value model clarifies that collection agents and repair facilities need information from manufacturers to support them in extending the lifetime of washing machines. Collection agents need product and usage information to perform the assessment. Repair facilities obtain product, usage, and repair information during the repair of washing machines. Because producers receive financial compensation for this information, which is discounted in the sales price, they are encouraged to share the information. Information sharing will tackle the current barrier of limited availability and accessibility of information for stakeholders of the washing machine ecosystem in the reverse supply chain. The availability of DPPs contributes to this information sharing and ensures that collection agents and repair facilities optimally fulfill their role from a circular context in which lifetime extension assessment and repair prevail. Thus, introducing DPPs supports the circular capabilities of collection agents and repair facilities. Strengthening the role of these actors contributes to strengthening a circular ecosystem in which extending the lifetime of washing machines is a collective value proposition.

Another customer need that triggers the EEE value network is the demand from materials suppliers for recycled materials. Government legislation is expected to make high-quality recycling of materials mandatory so that recycled materials form high-quality input for the next production cycle. The customer needs of materials suppliers trigger an interdependency path between materials suppliers – recyclers – collection agents – discarders. Financial-product transactions drive the value exchange between these actors. The materials suppliers supply recycled materials to manufacturers of washing machines. Because lifetime extension is central to the circular ecosystem, this value exchange between materials suppliers and a washing machine manufacturer has not been modelled.

A relevant consideration is the question of which customer needs dominate in the value model. Currently, financial incentives reward materials recycling. However, the value model assumes that consumers are willing to pay a higher product price because of the increased market demand for second-hand washing machines. The higher compensation this generates encourages repair facilities and collection agents to extend the lifetime of washing machines. At the same time, these considerations provide insight into the vulnerability of the elaborated value model. The amount of financial compensation ultimately determines whether the value exchanges between the actors in the value network are economically attractive. This requires mandatory circular economy regulations from governments aimed at extending the lifetime. Another condition is that manufacturers produce high-quality washing machines suitable for lifetime extension. A further vulnerability of the value model is that the actors in a value network must be willing to pay for information. Revision of laws and regulations is also necessary to be able to reuse harvested parts.

In addition to the introduction of DPPs, as outlined in the scenarios in **Section 3.1**, how the circular ecosystem will develop further is primarily determined by the application of digital technologies in washing machines, circular product design, and service-oriented business models. The second socio-technical scenario, where the current information asymmetry is canceled, might lead to a far-reaching disruption of the current washing machine ecosystem. This disruption may result in new players in the washing machine sector offering new services from a product lifecycle perspective. For example, new players offer services concerning (big) data analytics, smart maintenance, repair service provision, support centers, washing machine fleet management, service level agreements, and security services.

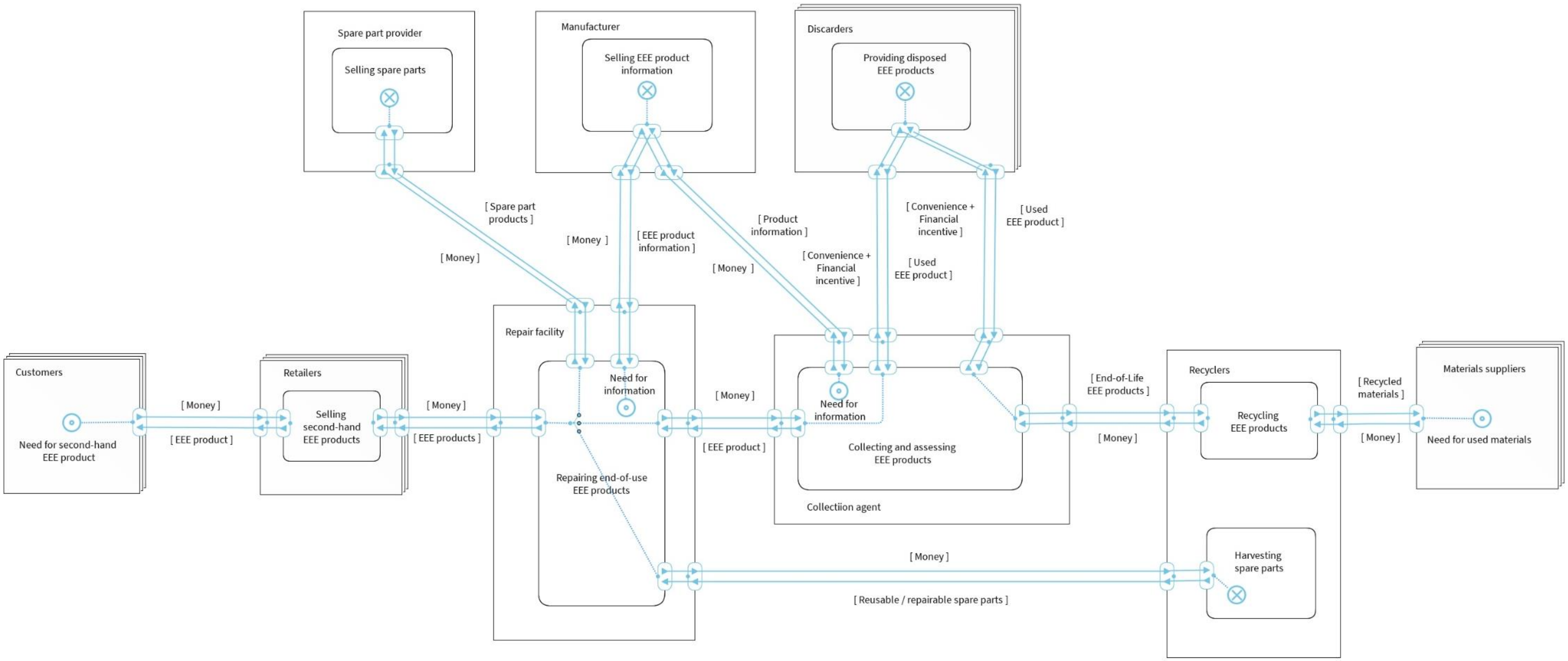


Figure 3-5: Elaboration on future value model

In such a circular ecosystem, the role of a collection agent, collecting and assessing washing machines, is closely intertwined with the roles of other stakeholders. Collectively, the circular ecosystem stakeholders collaborate to optimally utilize the residual value of a washing machine during a product life cycle. Exploiting the business opportunities offered by the lifetime extension value proposition is a critical driver for the circular ecosystem stakeholders and elicits additional value exchanges in the elaborated value model in **Figure 3-5**.

3.3 Summary and conclusion

The elaboration of the socio-technical scenarios above has provided insight into how the current socio-technical regime of the washing machine ecosystem can change. Technological innovation, product design, data governance, governmental policies and regulations, business model innovation, consumer behaviors, and value chain collaboration are all relevant factors. The accessibility of product and usage data is a critical differentiating factor in the socio-technical scenarios. The availability and accessibility of data determine whether the “end-of-use” potential of collected washing machines can be used. In the future, DPPs will be able to contribute to a rich information supply that supports the lifetime extension assessment of collected washing machines by collection agents. A literature study clarified that extending the lifetime of washing machines on a large scale is only possible if the washing machine ecosystem is approached from a system perspective. Circular washing machine ecosystems, in which extending the lifetime of washing machines is a collective value proposition of the value network actors, meet this condition.

In line with the principles of a circular ecosystem, the value model for the near future elaborated in **Section 3.2.3** has clarified the value exchanges between actors in a value network which contribute to a collective value proposition regarding lifetime extension. In addition to a significant market demand for second-hand washing machines, paying for information and making product, usage, and repair information more widely available enhance the viability of the modelled value network.

The insights gained in this chapter contribute to defining the requirements concerning the three system artifacts to be developed.

4 Requirements elicitation

This chapter presents the system requirements for the three defined system artifacts. **Section 4.1** explains the research approach underlying the requirements elicitation process. **Section 4.2** discusses the research findings with experts during work sessions that served as input for the developed system requirements. Existing system solutions concerning the assessment of returned products were also mapped out at five organizations, which can provide valuable insights for the system requirements to be defined. These research findings are discussed in **Section 4.3**. **Section 4.4** present the requirements concerning the information system for collection agents. **Section 4.5** explores the minimum acceptable residual lifetime of washing machines guiding the development of the assessment component in the current situation. **Section 4.6** presents the summary and conclusion.

4.1 Research approach

During three separate work sessions with three experts, system features and functionalities of the three system artifacts were outlined. **Table 4-1** shows the characteristics of the circular economy experts. These respondents are relevant because they are active in the waste management sector, have insight into electronic waste issues, and are circular economy experts.

Characteristics	Domain expert 1	Domain expert 2	Domain 3
Organization	Waste management company	Provincial network organization stimulating innovation in and between SMEs	Regional government
Role	Senior expert in the field of waste management policies and circular economy	Senior innovation and circular economy expert	Senior circular economy expert at regional government
Member of E-novation Hub	Yes	Yes	No

Table 4-1: Respondents work sessions

Additionally, four work sessions took place with the CirkelWaarde client to define the three sets of system requirements. The requirements are composed from the perspective of collection agents, such as municipal and commercial collectors. In the initial phase of the requirements specification, the emphasis during the two work sessions was on defining the functionalities of the system architecture for a collection agent and corresponding requirements. During one additional work session, these requirements were specified in the next phase. During a fourth work session, the lifetime extension assessment component and DPPs requirements were specified.

4.2 Domain expert views on system artifacts

Table 4-2 lists the main feedback points of the three respondents concerning the defined system artifacts for collection agents. The feedback in the table functions as input for the system requirement development in the next section.

Feedback	Domain expert 1	Domain expert 2	Domain expert 3
1. Consider a ‘funnel-wise’ process approach to clarify as early as possible whether lifetime extension of washing machine is possible.	X		
2. Develop a modular system of the system archicture of a collection agent to enable flexibility and to meet specific customer needs. Consider how the subsystem influence each other.			X
3. Determine minimal acceptable residual lifetime of a washing machine.	X		
4. Distinguish at high aggregation level a monitoring and control system responsible for transparency of and feedbackward & feedforward mechanisms in the assessment process.	X		X
5. Identify critical assessment criteria that reveal the feasibility of lifetime extension and objectify a specific circular strategy. For example, reuse or repair.	X		X
6. Consider for which stakeholders the lifetime extension assessment system will be developed.			X
7. Design a DSS encompassing critical norms enabling informed decision-making with regard to lifetime extension.	X	X	X
8. Investigate to what extent generic decisions can be made concerning the assessment of washing machines.	X		
9. Select high-quality reverse logistics channels to collect disposed washing machines	X		
10. Consider the harvesting of spare parts from end-of-life washing machines.	X	X	X
11. Consider whether the system has a static, generic or dynamic character and the consequences for the nature of the information provision and the DSS. In a dynamic data driven system each unique disposed washing machines follows a unique tailored-made process route.		X	X
12. If possible, standardize and systematize assessment process tasks.			X
13. Develop a system that in the end is self-learning and is continuous improving itself. The assessment of disposed washing machines and related processes, protocols and DSS, should become more intelligent.	X	X	X
14. Record data in a database management system enabling the storage, retrieval and modification of data.	X		X
15. To support the assessment process of a disposed washing machine, specify which information and data should be recorded in DPP.	X		X
16. Consider the applicability of data-analysis in a data-driven collection and assessment of disposed washing machines.		X	X
17. As part of the lifetime assessment, identify helpful information sources for data provision.		X	
18. Explore how the system provides specific instructions to employees at a collection point.		X	X

Table 4-2: Feedback work sessions

4.3 Requirements information system for collection agents

The work sessions with domain experts and client’s feedback contributed to the formulation of system requirements regarding information system for collection agents (see **Table 4-3**).

System requirements	Functional requirements	Non-functional requirements
1. The system shall enable the processing of a minimum of 500 disposed washing machines daily.		X
2. The system process activities shall take place at a regional level as far as possible to take advantage of geographical proximity and to minimize negative transport externalities.		X
3. The system shall allow future extension to other product categories of consumer electronics.		X
4. The system shall adress external developments required to viably implement the designed system.		X
5. The system shall be adaptive to continually improve process performance based on new information and data insights.		X

System requirements (*continued*)		Functional requirements	Non-functional requirements
6.	The system shall enforce that the minimum technical residual lifetime of a recovered washing machine corresponds to common warranty terms provided in business markets on reusable washing machines.		X
7.	The logic of the system shall be easy to understand for all supply chain partners involved.		X
8.	The system and underlying subsystems shall be modular to enable partial application of system services.		X
9.	The system shall direct the collected washing machines towards the highest possible circularity strategy in the waste hierarchy.		X
10.	The system shall provide insight into the potential circular strategies of collected washing machines as early and quickly as possible.	X	
11.	For each collected washing machine, the system shall enable dynamic tailor-made process decisions and a critical path in the process flow.	X	
12.	If the lifetime of a washing machine cannot be extended, the system shall stimulate the harvesting and reuse of frequently-used washing machine components during recovery.	X	
13.	The system shall contribute to increased awareness among discarders about their waste behaviors.		X
14.	The system shall describe relevant operational process activities aiming to extend the lifetime of collected washing machines.		X
15.	The system shall monitor and visualize the operational process performance.	X	
16.	The performed process activities in the system shall be transparent and traceable for supply chain partners involved.		X
17.	Currently, the system shall describe assessment process activities as generically as possible, only using product-specific information when necessary.		X
18.	The operational assessment process activities shall be standardized as much as possible.		X
19.	The system shall be data-driven and automated at the highest possible level.		X
20.	The system shall allow the public sharing of information and data.		X
21.	The system shall be supported by commonly used information technology systems that facilitate information & data exchange between various supply chain partners.		X
22.	The system design shall set favourable conditions to allow smooth integration with processes and systems of other EEE stakeholders.		X
23.	The system shall enable the integration of subsystems to ensure the overarching system's functionality.		X
24.	The system shall be secured against external digital threats that could compromise information security.		X
25.	At a central level, the system shall enable informed decision-making and deliver actionable information to (re)direct underlying subsystems if necessary.	X	
26.	The application of information processing technologies shall automatize the system much as possible		X
27.	The system shall allow the use of several underlying system applications simultaneously and at different locations.		X
28.	The system shall be self-learning and able to continuously improve itself.		X
29.	The system shall utilize data principles that enable machine-actionability and reuse of data.		X
30.	The system shall clarify what information and data are required when assessing disposed washing machines.		X
31.	The system shall incorporate effective data management to retrieve, store, organize and maintain data collected and created by the system.	X	
32.	The system shall facilitate access to external databases and websites that provide product-specific information about identified washing machines.	X	
33.	The system shall allow the processing of fluctuating volumes and different types of data.		X
34.	The system shall respect the GDPR regulations.		X

System requirements (*continued*)	Functional requirements	Non-functional requirements
35. The system shall convert available data into useful information that provides insight into the performance of assessment processes.	X	
36. The system shall contain a knowledge driven DSS that helps to systematically and objectively make tailor-made decisions in the operational processes.	X	
37. The system shall reveal the identification of discarded washing machines.	X	
38. The system shall request discarders to provide information about discarded washing machines.	X	
39. The system shall as systematically and easily as possible direct the technical diagnosis of disposed washing machines to gain insight into their technical states and potential malfunctions.	X	
40. Based on the results of the diagnosis of discarded washing machines, the system shall prescribe roughly standardized recovery work packages that direct the recovery of frequent errors of defective washing machines.	X	
41. Based on the results of the diagnosis of discarded washing machines, the system shall estimate to what extent product lifetime extension is technically and economically feasible.	X	
42. The system shall prescribe specific instructions to employees to support them during the execution of their assessment process activities.	X	
43. The system shall respect applicable safety and environmental regulations & professional standards when employees excecute operational work tasks.		X
44. The system shall include relevant information and data in a DPP to support data-driven lifetime extension assessment of discarded washing machines.		X

Table 4-3: Requirements information system for collection

4.4 Requirements lifetime extension assessment component

In this section the set of system requirements for a lifetime extension assessment component applicable in the short term is specified (see **Table 4-4**).

System requirements	Functional requirements	Non-functional requirements
45. Based on the information in DPPs, an assessment component shall enable transparent, informed decisions regarding possible lifetime extension of washing machines.	X	
46. The lifetime extension assessment component shall assess collected washing machine within a few minutes.	X	
47. The lifetime extension assessment component encompasses criteria with a high predictive value clarifying if lifetime extension is possible.		X
48. A lifetime extension assessment component shall utilize fruitful information sources to provide data to a DPP.		
49. If possible, the lifetime extension assessment component shall apply washing machine product and usage data enabling informed decisions concerning lifetime extension.	X	
50. The usage of the lifetime extension assessment component shall require limited technical knowledge about washing machines.		X
51. Digital applications supporting collection agents' employees in lifetime extension assessment of washing machines shall be easy to use and match their competencies.		X
52. The assessment component is applicable at multiple locations.		X

Table 4-4: Requirements lifetime extension assessment component

4.5 Minimum acceptable residual lifetime of washing machines

A critical system design consideration relates to washing machines' minimum acceptable residual lifetime. The minimum acceptance standard affects the warranty period and the assessment method. Therefore, insight into these warranty periods is relevant. The rigor of the lifetime extension assessment is influenced by the minimum required residual life of a washing machine. For example, if a collected washing machine has to last for at least another two years, a possible consequence is that a revision strategy is applied and parts are replaced preventively. If a washing machine has to last at least six months, a reuse strategy with a few technical checks on critical components will be sufficient. The expected period that a washing machine should function properly after lifetime extension assessment and possible repair or refurbishment might entail high costs. Thus, a high minimum acceptable functional time period puts considerable pressure on the economic viability of the lifetime extension activities. Interviews with the repairers in **Section 2.3** clarifies that the current product design of many washing machines does not provide lifetime extension, and the costs of the parts required are very high concerning the relatively low purchase price.

The current standard manufacturer's warranty for new washing machines is two years. Manufacturers often offer a long-term guarantee on the motor of a washing machine. Research on the websites of white goods sellers provided insight into common warranty periods of reusable washing machines among sellers (see **Table 4-5**).

Organization type	Warranty period	Explanation
Thrift store in collaboration with washing machine manufacturer	2 years	Refurbished washing machines. Access to product and repair information. Initial lifetime before refurbishment is about < 5 years.
Thrift store 1	1 month	Reusable and repaired washing machines
Thrift store 2	3 months	Reusable and repaired washing machines
Thrift store 3	1 month	Reusable and repaired washing machines
Thrift store 4	3 months	In collaboration with a national white goods dealer, discarded washing machines are repaired or refurbished
Thrift store 5	1 month	Reusable and repaired washing machines
Second hand white goods seller	3 – 6 months	Initial lifetime varies. Reuse, repaired and refurbished washing machines.
Second hand white goods seller	3 – 6 months	Initial lifetime varies. Reuse, repaired and refurbished washing machines.
E-commerce retailer	3 months	Refurbished washing machines
	2 years	Second chance washing machine sent back by previous customer
Manufacturer	1 year guarantee	Refurbishment washing machine program of German manufacturer

Table 4-5: Warranty periods of reusable washing machines

Table 4-5 shows that thrift store warranty for reusable and repaired washing machines varies between one and three months. The age and usage history of the used washing machines sold by thrift stores vary considerably, resulting in a short warranty period. Commercial second-hand white goods sellers offer a three- or six-month warranty. A large E-commercial retailer, in collaboration with a third party, offers refurbished washing machines that have a warranty period of 3 months. A recycling company with a partnership with washing machine manufacturers offers a warranty period of 2 years for refurbished washing machines per the manufacturer's warranty. The relatively young age of these washing machines and the access to the manufacturer's repair facilities make this warranty period possible. A German manufacturer of washing machines recently started a refurbishment program that offers a 1-year warranty on appliances.

In consultation with the client, it was decided that the lifetime extension assessment component should aim for a warranty period of at least six months in the current situation. This time frame was selected because comprehensive lifetime stretching of washing machines requires overhaul and repair strategies that are economically and technically feasible to a limited extent. Possible future circular product designs of washing machines that are suitable for repairability and therefore entail lower repair costs might contribute to the economic attractiveness of lifetime extension. Such a shift in product design might stimulate a product repairer to issue a more extended warranty period. Consequently, longer warranty periods may be feasible in the future.

4.6 Summary and conclusion

In this chapter, the requirements concerning the various system artifacts are elaborated. For this purpose, work sessions were held with experts in the initial phase of the requirements elicitation process. The main goal was to develop a system vision on lifetime extension issues for collection agents. In addition, research has been carried out at specialized organizations in return logistics of consumer electronics and the assessment of returned products for lifetime extension (see **Section 2.4**). Based on the insights that both design research activities have yielded, 52 requirements have been defined in consultation with the client. Forty-four of these requirements relate to the lifetime extension information system for collection agents. The other requirements concern specifications of the assessment component. During the system development process, due to the expected impact, the choice was made to abandon the original focus on product repair completely and to focus on the collection of discarded washing machines. A guiding principle during the design process of the system artifacts was the acceptance standard with regard to the minimum acceptable residual life of a washing machine. This standard has far-reaching consequences for the assessment method, the scope of the technical repair activities, and the amount of the related repair costs.

5 Lifetime extension information system for collection agents

This chapter explains the design of the information system for collection agents. **Section 5.1** presents the methodical justification of the design. **Section 5.2** outlines the information system for collection agents, the decomposition of the system elements, its functions, and the underlying design decisions. **Section 5.3** summarizes and concluded the chapter.

5.1 Design method approach

Figure 5-1 illustrates how the system development process of the information system for collection agents came about. The information system can be positioned in the context of the developments described in the detailed socio-technical scenarios (see **Section 3.1**). In line with the transition to a circular economy, the information system for collection agents operates transitionally from the socio-technical regime towards a partial circular economy by 2030. Influenced by the EU's Green Deal policies, DPPs are assumed to be increasingly mandatory. Given the product characteristics of the current washing machine range, many washing machines can be assumed to be equipped with digital technologies. Such technologies enable insight into historical usage and keep track of any failures. At the same time, many washing machines currently collected by collection agents will be mechanical and lack digital applications. This lack of digital applications hinders digitization and datafication possibilities. The current identified system solutions for assessing returned electronic products at five case study organizations addressed the possibilities of digitization (see **Section 2.4**). Initially, working sessions with circular economy and waste management experts have made a critical contribution to the vision of an information system for collection agents (see **Section 4.2**). In addition, the defined system requirements formed critical input for the system development process.

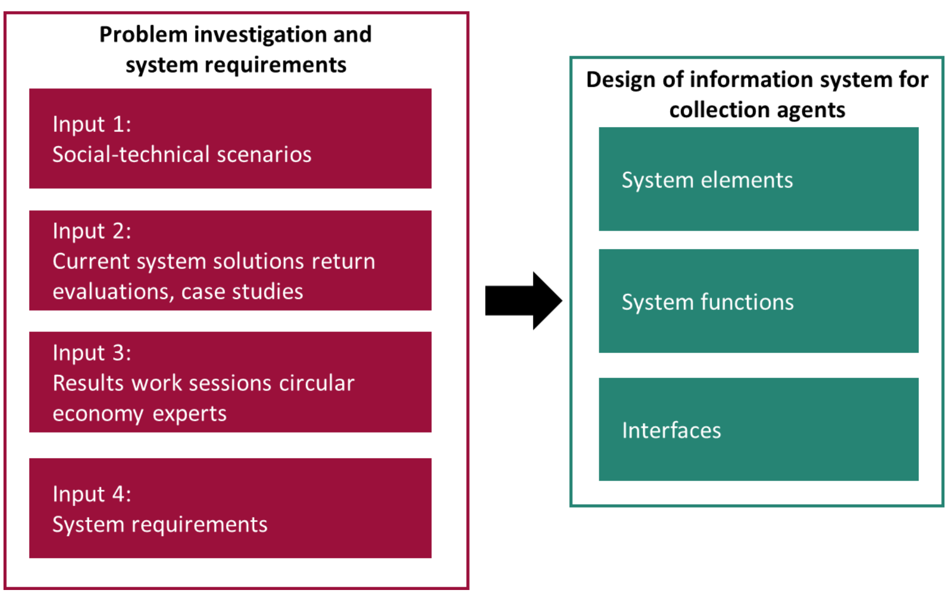


Figure 5-1: Process approach for system design and development

Based on these three inputs, an overarching vision for a lifetime extension information system for collection agents was drawn up. Then the information was decomposed into system components. The essential functions of the system components are listed here. During the decomposition process, the relationship between the inventoried system solutions in the case studies, the expert work session results, and the system requirements was made explicit. In outline, the behavioral aspects of the interfaces between the system components and the user interfaces were inventoried.

5.2 Information system design for collection agents

Figure 5-2 is a visual representation of the information system developed for collection agents. The purpose of the information system for collections agents is to assess whether collected washing machines are eligible for lifetime extension. Collection agents also want transparency in the assessment process. This transparency relates to the machine's receipt, registration, and assessment results. In this study, collection agents and their employees are regarded as the primary users of the information system. However, governments are also interested in the transparency of such assessment results in their management of the transition to a circular economy. In addition to collection agents, governments would like to know how many collected washing machines arrive at a collection agent, what their product properties are, and whether their lifetime extension is feasible.

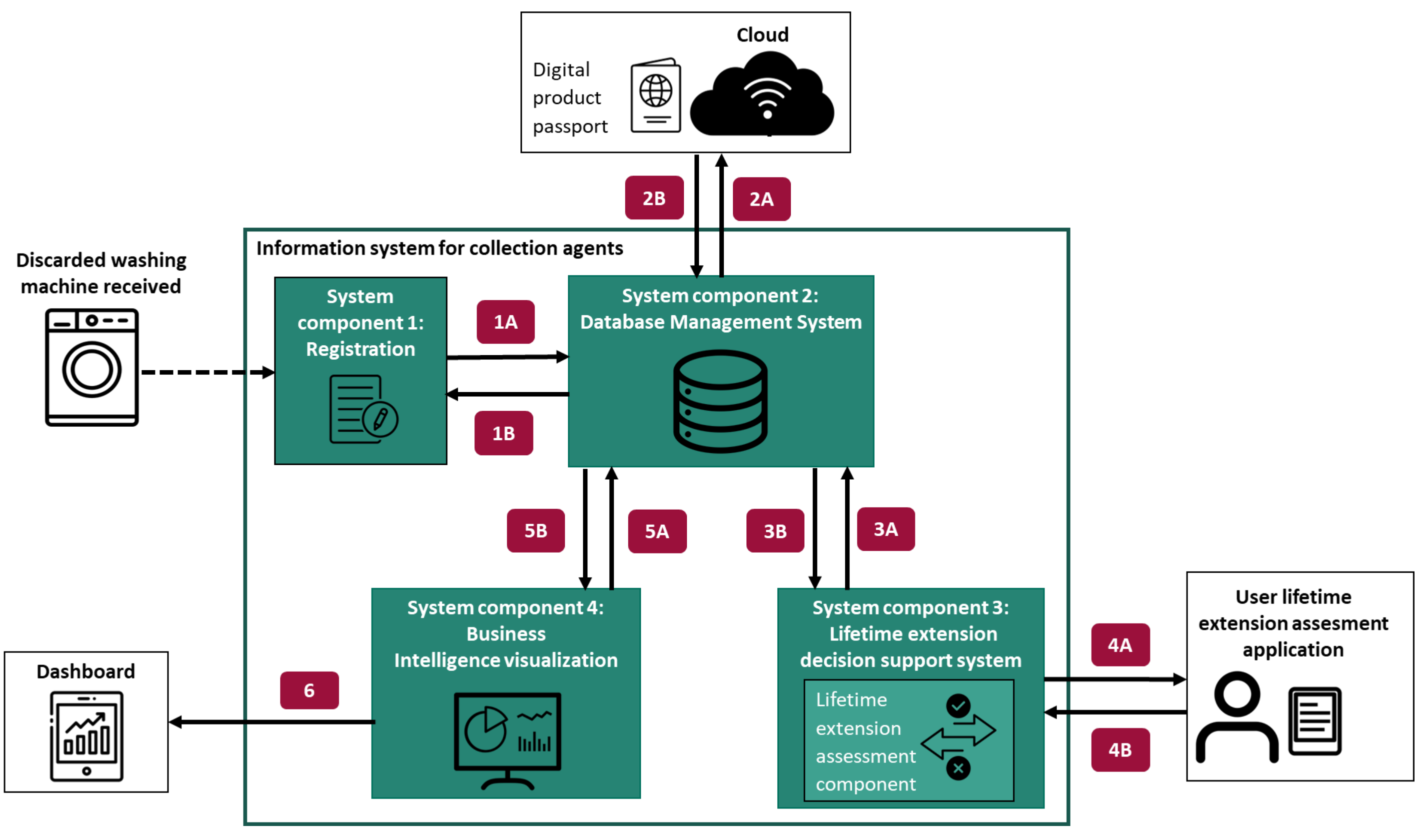


Figure 5-2: Design of information system for collection agents

5.2.1 Design considerations

An initial requirement was that the information system for collection agents should explicitly indicate, as output, a suitable circular strategy for washing machines, including Reuse, Repair, or Refurbishment. However, during the system development process, it became clear from interviews with repairers that the number of brands and product types of washing machines is vast. A differentiation towards circular strategies also requires that all washing machines are equipped with digital technologies by 2030, enabling product and usage data. The generation of washing machines currently in circulation often does not contain these digital technologies or only has them to a limited extent. An information system that aims to select a specific circular strategy for a collected washing machine requires an extensive and complex assessment process. Defining appropriate parameters and standards that justify a specific circular strategy for a washing machine is complex, given the considerable number of technical, economic, market, and environmental factors that influence such a decision. This complexity is at odds with the client's requirement to develop a simple assessment that provides insight into the probability of lifetime extension based on a limited set of parameters. Based on these considerations, in consultation with the client, the choice was made to focus the information system's outcome primarily on the dichotomous choice of whether lifetime extension is promising or not.

The event that triggers the information system originates in the delivery of a collected, discarded washing machine. An employee at the collection agent receives the device and registers it. The essence of the information system is that it assesses a collected washing machine for lifetime extension and presents the assessment process results visually. A washing machine eligible for lifetime extension is selected for subsequent reuse, repair, or refurbishment. Specification of these follow-up process activities falls without the scope of this study.

5.2.2 Information system components

Table 5-1 specifies the system components and the functions performed by each system component. The table also clarifies the identification process of the defined system components. To this end, specific emphasis fell on how the work session results from experts, system requirements, and case study results contributed to the definition of each system component. The information system for collection agents comprises four components: a registration component, a database management system (DBMS), a lifetime extension DSS, and a business intelligence visualization component. These system components interface externally with user apps in the cloud. **Table 5-2** describes the functions and relevant system requirements of the external interfaces as part of the information system for collection agents. **Table 5-3** specifies the internal and interfaces between system components and external user interfaces.

Component / subsystem	Explanation	Functions	Relevant system requirements
1. Registration	Registration and identification of collected washing machine	- Product identification	37 (identification of discarded products)
2. DBMS	A computerized data-keeping system to create, edit, and maintain database files and records	- Data storage management - Data analytics management - Data integration management - Backup and recovery management - Security management	5 (system adaptivity) 19 (data-driven, automated system) 22 (system & data integration) 24 (digital threats) 29 (data quality) 30 (required assessment data) 31 (data management) 33 (processing data) 34 (GDPR compliance) 35 (data conversion into information) 49 (product and usage data)
3. Business Intelligence visualization	Visual presentation of performance of lifetime extension information system	- Assessment performance visualization on dashboards	15 (visualization assessment performance) 16 (transparency assessment process activities) 20 (public sharing assessment information)
4. Lifetime extension decision support system	A computerized information system that supports collection agents in their decision-making activities concerning lifetime extension of washing machines.	- Lifetime extension assessment - Knowledge management - Inference engine, model base, control system	5 (system adaptivity) 6 (minimal acceptable residual lifetime) 9 (highest circular strategy) 10 (quick check of feasibility of appropriate circular strategy) 11 (dynamic character, critical path assessment process) 14 (operational process activities) 18 (standard process activities) 25 (informed decision making) 28 (self-learning system) 30 (required assessment data) 36 (knowledge driven decision support) 39 (product diagnosis) 41 (feasibility of lifetime extension) 45 (informed decisions) 46 (assessment in limited time) 47 (assessment criteria) 49 (application of product and usage data) 50 (limited technical knowledge) 51 (usability for employees) 52 (applicability at multiple locations)

Table 5-1: Decomposition of information system for collection agents

External user interfaces	Explanation	Functions	Relevant system requirements
5. Cloud / DPP	DPPs contain product lifecycle information of washing machines, shared across the washing machine circular ecosystem. The DPPs are stored in the cloud. The cloud refers to servers accessed over the Internet.	- Digidentity / product identification - Data storage management - Data analytics management - Data integration management (external information sources) - Backup and recovery management - Security management	3 (extension to other product categories) 32 (access to external databases and websites) 44 (data in DPPs supporting lifetime extension assessment) 45 (DPP data enable informed-decisions) 48 (information sources as input for DPPs)
6. User lifetime extension assessment application	A user application instructs a collection agent to perform assessment process activities. Input on the application is the input for the DSS.	- Prescription of assessment process activities	42 (instructions for employees) 50 (limited technical knowledge) 51 (competencies of employees) 52 (applicability multiple locations)
7. User Business Intelligence visualization	Presents assessment process KPI data on a BI dashboard.	- Visualization	15 (visualization assessment performance)

Table 5-2: External interfaces of information system for collection agents

Interface nr	Interface	Explanation
1A	DBMS - Registration	DBMS requests registration data on collected washing machine.
1B	Registration - DBMS	Registration data of collected washing sent to and stored in DBMS.
2A	DBMS – DPP / Cloud	DBMS triggers specific DPP in the cloud. DBMS add data to DPP.
2B	DPP / Cloud – DBMS	DBMS retrieves data from specific DPP to DBMS.
3A	DSS – DBMS	DSS requests relevant data from DBMS to perform lifetime extension assessment.
3B	DBMS – DSS	Results of lifetime extension assessment are sent to DBMS.
4A	DSS – User assessment application	DSS sends instructions to a user application for employees to perform lifetime extension assessment. DSS sends results of lifetime extension assessment to user application.
4B	User assessment application - DSS	User application sends performed results of assessment (e.g., visual checks of washing machines) to DSS.
5A	DBMS – BI visualization	BI visualization sends request to DBMS for KPI data to visualize assessment process.
5B	BI visualization - DBMS	DBMS sends required KPI data for BI visualization.
6	BI visualization – BI dashboard	BI visualization sends KPI data to dashboard.

Table 5-3: Interfaces specifications

Registration

The registration component ensures the correct registration of a collected washing machine. This registration involves primary data such as reception location ID, reception date and time, collection agents' employee ID, and logistics data being recorded in the information system. When registering a washing machine, the unique identity, the digidentity, of the device must be identified. To perform this action, an employee must scan the unique product identifier of a washing machine (such as its barcode). The identifier is linked to a DPP in the cloud. Older appliances may require an employee to manually register the identity of the washing machine by entering the brand and model type codes. The registration component interfaces with a DBMS. The DBMS then requests registration data about the collected washing machine (user interface 1A). This interface also ensures that the product identity becomes clear immediately after registration. Determining a washing machine's unique product identity must be done before performing a lifetime extension assessment, because its unique identity enables access to a specific DPP that matches the collected washing machine. The washing machine's registered data are then stored in a DBMS (interface 1B).

Database Management System

The computerized DBMS occupies a central place in the information system: it stores, retrieves, and manages the collected washing machines' product and historical data. The data from collected and assessed washing machines are stored in the DBMS, where a database engine is responsible for creating, extracting, reading, manipulating, editing, and deleting data. The database contributes to data security, integrity, compatibility, and uniform data administration procedures. The structure of the DBMS is organized by a data model type, such as a relational, distributed, or object-oriented model. The DBMS requires clear agreements on aspects of data governance to ensure data quality, database operations, data storage, data accessibility, data modification, and data security. Different data types from different information sources are combined as appropriate input for the DSS.

DPPs

User interfaces allow data to be created, read, updated, and deleted by authorized entities in the cloud. Much of the product life cycle data required during the lifetime extension assessment of the washing machines are recorded in the DPPs. An interface with the cloud connects to the data in the DPPs (interface 2A). The collection and provisioning of product lifecycle data on washing machines is also recorded in the DPP. The more it is affected by digital technologies such as Internet of Things technologies in washing machines, the DPP will increasingly take on a more dynamic character. Therefore, the design decision was to locate the DPPs in a central cloud accessible to relevant washing machine ecosystem stakeholders such as manufacturers, retailers, repairers, and collection agents. The washing machine stakeholders can add, extract and edit data from the passport during the product life cycle of a washing machine. The cloud also encompasses external information sources that provide the DPPs with information, such as the European Product Registry for Energy Labeling and links with washing machine manufacturers for obtaining product information. Relevant assessment data from DPPs in the cloud are temporarily stored in the DBMS via an interface within the cloud (interface 2B).

Data analytics

Another function of the DBMS concerns data analytics. Assessments of large numbers of collected washing machines generate a large stream of raw data. Proper aggregation and analysis of this raw data can provide valuable insights into the assessment process, the product characteristics of the collected washing machines, and the performance of the assessment process itself. These insights can be fed back to relevant stakeholders in the collection agent’s washing machine ecosystem. For example, if a collection agent receives many washing machines of a specific brand and product type that break down prematurely, they can feed these insights back to a manufacturer.

Decision Support System

A computerized DSS component enables objective dichotomous informed decisions on lifetime extension. The DSS consists of a knowledge base, a model base, and interfaces to the DBMS and a user lifetime extension assessment application. The DSS requests from the DBMS the data necessary for informed decision-making (user interface 3A). The assessment criteria determining the lifetime extension of collected washing machines are key to the DSS. **Table 6-2** presents an overview of relevant assessment criteria for decision-making, such as washing machine properties, performance, current status, repair history, and sustainability aspects. In a knowledge base, the DSS captures the knowledge to support lifetime extension decision-making, such as the knowledge of manufacturers, retailers, and repairers. Other relevant knowledge is concerned with economic, ecological, technical, technological, sustainability, circular, and social factors. In the DSS, knowledge is encoded as rules. For example, washing machines from a particular brand or with specific failure modes are not repairable. In addition to using simple static rule-based knowledge, the DSS uses analytical models and statistical tools to support informed decision-making. The information system for collection agents becomes intelligent because an inference engine allows new knowledge to be inferred in the knowledge-based system. The inference base contributes to the dynamic character of the information system for collection agents and enables unique, dynamic assessment process routes for each washing machine. The actual assessment of washing machines in the DSS is part of the lifetime extension assessment component. According to an assessment process in which each assessment criterion is tested against the available data from the DBMS and the modeled data from the inference base, the eligibility of a washing machine for lifetime extension possibilities is determined.

User lifetime extension assessment application

The assessment is partially dependent on input from a collection agent employee. For example, visual checks and critical technical tests (such as a bearing test) can be part of the lifetime extension. Via a user interface (interface 4A), the DSS requests that an employee carry out specific prescriptive instructions. The employee receives a notification of this request on a mobile smartphone or tablet on a user lifetime extension application. The employee then enters the requested results on the smartphone or tablet. The entered results are sent to the DSS via a user interface (interface 4B) and included in the lifetime extension assessment process. As the lifetime extension assessment system processes vast amounts of collected washing machines, the system becomes progressively more intelligent. The DSS allows feedback and feed-forward control mechanisms to optimize the assessment process.

The results of the lifetime extension assessment in the DSS are sent to the DBMS (interface 3B) and are recorded in the DPP via interface 2A.

Business Intelligence visualization

The Business Intelligence visualization component presents assessment performance on dashboards to ensure transparency of the assessment process. The BI visualization component requests, via interface 5A, specific data from the DBMS on critical KPI parameters. The required data from the DBMS are delivered to the BI visualization component via interface 5B. The primary function of the BI component is to transform data into meaningful information that can be presented on dashboards. Via user interface 6, the dashboard presents KPI data from the assessment process, such as the number of collected washing machines, the number of washing machines that are eligible for lifetime extension, the collected washing machines' year of construction, common washing machine brands and the specific assessment results (e.g., common causes of defective washing machines that are not eligible for lifetime extension and the circularity performance of collected washing machines). The information is made visible on a BI dashboard via a user interface. This dashboard is then visible to collection agents' employees. The assessment process information is also reported to the authorities.

5.3 Summary and conclusion

The information system designed for collection agents shows how collected washing machines can be assessed for lifetime extension. The application of DPPs as a data carrier plays an essential role and allows a data-driven, objective assessment of washing machines. Essential system components of the information system are a Registration System, a DBMS, a DSS, and a Business Intelligence Visualization. External interfaces allow interaction between the information system with a cloud in which the DPPs are stored, a user application that gives instructions to employees of a collection of agents, and a visual dashboard that presents the performance of the lifetime extension assessment. Deployment of the information system simultaneously at multiple locations of collection agents is possible.

The information system designed for collection agents still requires the addition of some concrete details. The problem investigation in **Chapter 2** and the socio-technical scenarios in **Chapter 3** clarified that the lifetime extension assessment, as part of the DSS, depends on the availability and accessibility of data. While concretizing the design of the lifetime extension assessment component, an assessment component and process for a 2030 scenario are outlined in **Chapter 6**. The possibilities offered by the decision support data in the DPPs make an informed decision on lifetime extension transparent and objectified. Bound by the current restrictions on data availability and accessibility, an assessment component and process has been developed for the short term in **Chapter 7**. This development partially implements the information system for collection agents detailed in this chapter.

6 Lifetime extension assessment component scenario 2030

As a strategic part of the elaborated information system for collection agents in **Chapter 5**, this chapter presents a future lifetime extension assessment component and a related assessment process diagram. In line with the detailed socio-technical scenario in **Section 3.1.3**, full data availability and accessibility are assumed. The data allow the application of DPPs.

Section 6.1 explains the design research methods used to identify lifetime extension assessment criteria and to develop a DPP for washing machines. **Section 6.2** identifies the assessment criteria that are decisive for making informed decisions about the lifetime extension of washing machines. **Section 6.3** outlines use cases and the general data structure of the DPP. **Section 6.4** presents the validation of the elaborated use cases and the DPP. **Section 6.5** describes feedback points enabling refinement of the DPP. **Section 6.6** shows the final data structure of the DPP. **Section 6.7** outlines a process diagram clarifying how data-driven lifetime extension assessment occurs. Finally, **Section 6.8** present a summary and conclusion.

6.1 Design research approach

6.1.1 Assessment component functions

The lifetime extension assessment component is part of a DSS (see **Figure 5-2**). The function of a lifetime extension assessment component is that it executes a decision process. The decision process must objectify a decision as to whether extending the lifetime of a collected washing machine is feasible or not. This objectification depends on input data. Under the influence of EU Green Deal regulations, these data will be recorded in DPPs in 2030. These passports act as a data carrier over a washing machine's entire product life cycle. The decision-making process is structured based on assessment criteria. These assessment criteria require specific data. Thus, assessment criteria and data in a DPP are needed to make an informed decision about lifetime extension. Users can be linked to this DPP. The product life cycle perspective is relevant here to add and extract data during various phases in a life cycle of a washing machine. The data generated during a product life cycle of a washing machine in a DPP, as part of the assessment component, are extracted during a decision process and helps to check each assessment criteria. In this assessment, standards must be defined for each criterion to determine whether a particular data value linked to a specific assessment criterion is acceptable.

The design process of an assessment component requires the following design research activities:

- Determining the assessment criteria and corresponding data needs leading in the decision-making process.
- Elaborating use cases that clarify which users add data to and extract data from a DPP for washing machines.
- Elaborating a data structure of a DPP.

- Defining a process diagram that provides insight into the assessment process and provides for the presence of DPPs for washing machines.

6.1.2 Research design assessment criteria

The identification of relevant lifetime extension assessment criteria is based on a data triangulation approach, whereby participatory observations, semi-structured interviews with repairers, document analysis, and literature review (see **Section 2.2**) were conducted. Participatory observations took place at thrift store technical workshops which repaired collected washing machines and other consumer electronics. For two years, the researcher systematically observed, on average once a month, the repairers' product repair activities. These observations clarified which washing machine parts often break down and addressed product quality issues affecting the lifetime of the washing machines. Furthermore, with the aid of a professional repairer, the construction of five washing machines was thoroughly investigated. One washing machine was completely dismantled. Despite the variety of brands and product types, the construction of the washing machine is almost the same. Most washing machines have a motor with a carbon brush. In addition, younger generation washing machines have an electromagnetic, carbon brushless washing machine. The sample of five washing machines represented this limited variety in construction.

Systematic observations at a collection agent contributed to the identification of critical factors affecting lifetime extension. Semi-structured interviews with repairers on the subject of the repairability of washing machines also provided insight into critical lifetime extension assessment factors (see **Section 2.3**). As part of a document analysis, ten washing machines' product manuals were reviewed. In consultation with a professional repairer, this number of product manuals sufficiently represents the variety of product and performance specifications. The manuals contain product specifications, failure diagnostic information, and repair instructions. Additionally, on the websites of three E-commerce retailers selling consumer electronics, the product specifications for ten washing machines were determined. Finally, the literature review provided further insight into the identification of relevant lifetime extension assessment factors (**Section 2.2**).

The identified lifetime extension assessment criteria are operationalized in indicators. For each indicator, appropriate information sources for obtaining the required data have been examined. The indicators and information sources have been developed in anticipation of the current information asymmetry in which collection agents have limited access to product and usage data. Therefore, in preparation for developing the assessment component in the current situation (see **Chapter 7**), secondary indicators have been identified. Promising information sources have also been mapped out for these secondary indicators.

6.1.3 Research design use cases and digital product passport

Several research steps contributed to the conceptualization of a DPP for washing machines (see **Figure 6-1)**.

Figure 6-1: Design research methods for developing a digital product passport

Analyses of the washing machine ecosystem revealed that a systemic and holistic perspective on a circular economy in the WEEE industry stimulates the lifetime extension of collected washing machines (Bressanelli, Saccani, Pigosso, et al., 2020). Such an integrated perspective requires a product life cycle approach to washing machines. Each washing machine ecosystem stakeholder associated with a specific product life cycle stage provides data about a washing machine recorded in a DPP. The first research step therefore involved the identification of relevant EEE stakeholders which could benefit from a DPP. The ecosystems stakeholder analysis in **Section 2.1** was used for this purpose. In consultation with the client, four critical EEE stakeholders were selected. Manufacturers of washing machines are responsible for designing and producing washing machines that last a long time. Retailers sell new and used washing machines. Repairers extend the lifetime of washing machines after use. Collection agents are responsible for evaluating discarded washing machines for possible lifetime extension.

In the second research step, a systematic literature and document analysis was completed to determine the content of the use cases and the information needs of the selected EEE stakeholders. Relevant topics in the literature study were "Circular Economy," "Circular Business Models," "Circular Product Design," "Repairability," "WEEE Management," and "Return Evaluation." As part of a document analysis, circular policy documents from European and national governments as well as the EEE sector were analyzed.

In the third research step, four use cases were defined for each selected EEE stakeholder based on the literature review and document analysis in **Chapter 2 and 3**. The use cases illustrate the practical relevance of the DPP for washing machines and cover essential information about a washing machine's product lifecycle. The use cases address potential lifetime extension-related decision-making situations and also explain the information needs of each selected stakeholder. The stakeholders' information needs structured the DPP content. In addition to stakeholders' information needs, the information recorded in a DPP benefits the lifetime extension assessment of collected washing machines. The use cases were submitted for validation to two senior circular economy experts within a waste management organization.

In the fourth research phase, a DPP for washing machines was conceptualized based on the use cases. The primary function of the DPP for washing machines in this study is to support the lifetime extension assessment process of collected washing machines. The DPP study by Berger et al. (2022) especially contributed to operationalizing the information categories and related data properties in the passport. According to an iterative process, the data structure and data properties were defined together with the client during two work sessions. The information categories were schematized in a classification structure to represent information and data in the DPP. A first draft of the DPP was submitted to the client, a circular economy expert, for validation. The DPP was then submitted for validation to a senior expert in waste management and the circular economy. Based on this feedback, the data structure of the passport has been adjusted.

In the fifth research step, the most common use cases and the DPP are validated by the four selected EEE stakeholders active in the washing machine sector (see **Table** 6-1 **6-1**).

	Respondents		
Use case	**Respondent 1**	**Respondent 2**	**Respondent 3**
1. Manufacturer	X		
2. Retailer		X	X
3. Repairer		X	X
4. Collector		X	

Table 6-1: Respondents validation of use cases DPP

Respondent 1 is active as a senior innovation manager at a Dutch manufacturer and importer of consumer electronics. The innovation manager has over 20 years of experience in the EEE industry. The manufacturer use case was submitted to this respondent. Respondent 2 is head of a repair facility for 10 years and directs the product recovery of collected consumer electronics. This respondent is also responsible for selling and collecting consumer electronics at the collection point. The retailer, repairer, and collection agents use cases were presented to respondent 2. Respondent 3 is an operational manager at a retailer providing consumer electronics and repair services to B2C customers. This respondent has over 10 years of experience in the EEE retail. The retailers and repairer use cases were submitted to this respondent.

Figure 6-2 presents the validation methodology steps of the use cases and DPP. In research step 1, the use cases and the DPP for washing machines were emailed to the four respondents. The email contained instructions to the respondents for checking whether the use cases and the DPP reflected their future role in a 2030 scenario and the related information needs. In research step 2, a semi-structured interview was conducted with each respondent during a validation session. The interview consisted of three parts. In the first part, respondents were asked to what extent they recognized their future role in the use case(s) and related information needs. The interview questions for the second part related to the evaluation of the DPP. The respondent was asked to assess the relationship between the information needs in the use cases and the information in the DPP. The respondent was also requested to assess to what extent the information and data properties in each information category in the DPP matched their future information needs, as outlined in the use cases. Finally, the respondent was invited to provide recommendations on which information might increase the value of the DPP. In the third part of the interview questionnaire, the respondent was asked to prioritize the information categories and sub-information categories in the DPP according to the MoSCoW (must have, should have, could have, won't have) classification. This prioritization helped to understand the importance the respondents would place on the delivery of each information category over time.

Figure 6-2: Validation procedure of use cases and DPP

In step 3, the research results from the semi-structured interviews were documented and analyzed. Based on these research findings and analyses, the use cases and DPP for washing machines were finalized in step 4.

6.1.4 Research design decision process

A decision process has been designed based on the identified assessment criteria and the data in the DPP. During a working session with the client the guiding principles of the decision process were established. Based on these principles, the decision process has been structured with the client, and the role of a DSS has been addressed. Simultaneously, for every process step in the assessment has been pinpointed which data should be extracted from the DPP.

6.2 Identification of lifetime extension assessment criteria

Table 6-2 presents an overview of the lifetime extension assessment criteria identified in this study. The assessment criteria are the prelude to formulating specific data needs for assessing collected washing machines. The criteria apply to washing machines at the product level. Due to the focus of this study, the assessment criteria have not been elaborated at the component and the material level. The assessment criteria can be traced back to the assessment categories of product characteristics, washing machine health, value chain actors, environmental aspects, and market demand. Product characteristics of a washing machine provide insight into the product quality, physical product properties, and product performance specifications. Assessment criteria related to the washing machine's health refer to the device's physical condition, its completeness, failure diagnostics, usage intensity, repair history, and residual lifetime. The professionalism of EEE stakeholders during a product life cycle of a washing machine might affect its lifetime extension. Other factors touch on the environmental impact of collected washing machines and their possible lifetime extension. Circular product design and product repairability are determining factors in this respect. Expected market demand is another relevant factor affecting the desirability of lifetime extension. Furthermore, **Table 6-2** briefly explains the relevance of each assessment criterion and substantiates which research method underpins the selection of a criterion.

For each assessment criterion in **Table 6-2**, it has been specified which data are required to test an assessment criterion. For this purpose, a distinction has been made between primary and secondary data indicators (see **Appendix D)**. Primary data indicators represent the direct data needs to test an assessment criterion. If these data are unavailable, an assessment can occur based on secondary indicators. These primary indicators are particularly relevant in a data-driven assessment of collected washing machines. Secondary data indicators have also been elaborated. This group of indicators represent derived data needs that allow indirect testing of the defined assessment criteria. The current limited availability and accessibility of data that hamper collection agents from performing an adequate lifetime extension assessment urge the definition of the secondary indicators. Hence, these secondary indicators are relevant when elaborating on the assessment component for the current situation (see **Chapter 7**). For every primary and secondary data indicator has been specified which information and data sources allow information and data retrieval or how the desired data can be generated (for example, by performing visual checks).

			Author's own work			
Assessment categories	**Assessment criteria**	**Relevance**	**Participative observations**	**Interviews**	**Document analyses**	**Literature review**
1. Product characteristics	Product quality	The product quality of the materials, parts, connectors and the product as a whole affects the washing machine's lifetime	X	X		
	Physical product properties	Type washing machine. Compared to top loaders, the market demand for front loaders is high. Product features on a washing machine, such as load weight, method of operation, and washing programs, contribute to the extent to which a product is attractive to potential customers	X	X		
	Product performance specifications	Technical performance specifications, such as spin speed, washing result, energy efficiency, and water consumption, contribute to the attractiveness of a product to potential customers	X	X	Product manuals, E-commerce websites	
2. Washing machine health	Product status	Functioning signals indicate whether the device is viable	X		Product manuals	
	Physical condition of device	The physical condition of a washing machine is determined by its external and internal visual appearance	X	X		(Stamminger et al., 2020; Stamminger et al., 2018)
	Completeness of washing machine	The completeness of a washing machine affects whether additional spare parts are required to enable product repair	X			
	Failure diagnostics	Based on the failure diagnosis, current and previous failure modes are identified. The diagnosis allows the definition of possible recovery activities	X	X	Product manuals	(Bracquene et al., 2021; Tecchio et al., 2019)
	Delivered performance	The performance a washing machine delivers after a period of use	X	X		(Berger et al., 2022)

(*continued*) Assessment categories	Assessment criteria	Relevance	Author's own work: Participative observations	Interviews	Document analyses	Literature review
	Repair history	Insight into previous repair activities connected to recovered failure modes provide insight into the condition of a washing machine	X	X		(Berger et al., 2022)
	Maintenance history	The extent to which previous users of washing machines carried out regular maintenance activities to keep the washing machine in good working order	X	X		(Berger et al., 2022)
	Usage intensity	The frequency of use and past frequently selected washing programs	X			
	Treatment behaviors	How a previous user physically treated a washing machine affects its residual life	X			
	Availability of product and repair support information	The extent to which product and repair information is available and accessible to repair service providers influences the repairability of a washing machine	X		Product manuals	(Bracquené et al., 2018; Bracquene et al., 2021)
	Spare parts	The extent to which spare parts are still available after several years impacts the repairability of washing machines	X	X		(Bracquené et al., 2018; Bracquene et al., 2021)
	Economic feasibility of repair	Possible repair costs affect the economic feasibility of lifetime extension	X	X		
	Residual lifetime	The number of performed wash cycles of a washing machine and its age affect its residual lifetime	X	X		
3. Value chain actors	Value chain actors' professionalism	Value chain actors involved in a device during the product life cycle (e.g., manufacturers, retailers, repairers, and resellers) provide insight into responsible actors in a washing machine's life. E.g., compliance with regulations	X			(Berger et al., 2022)
4. Environmental aspects	Environmental performance	Energy and water consumption determine the ecological impact regarding lifetime extension	X			(Berger et al., 2022)
	Environmental impact	Life cycle analysis provides insight into the extent to which lifetime extension is acceptable from a sustainable and circular perspective				(Alejandre et al., 2022; Berger et al., 2022)
	Circular product design strategies	The leading design strategy of a washing machine influences the durability and repairability of washing machines				(Bakker et al., 2014; Bocken et al., 2016; Den Hollander et al., 2017)
	Product repairability	The repairability score determines the extent to which a washing machine is repairable				(Bracquené et al., 2018; Bracquene et al., 2021; Cordella et al., 2019; Cordella et al., 2018)

(*continued*) Assessment categories	Assessment criteria	Relevance	Author's own work: Participative observations	Interviews	Document analyses	Literature review
	Social impact	The extent to which lifetime extension contributes to inclusive personnel policies	X			(Luthin et al., 2023; Mies & Gold, 2021; Padilla-Rivera et al., 2020)
5. Market demand	Expected market demand	Quantified expected market demand for washing machines, differentiated by brand and product type		X		
	Expected pricing	The expected price at which a reusable washing machine can potentially be sold affects the economic attractiveness of lifetime extension			E-commerce websites	

Table 6-2: Identification of lifetime extension assessment criteria

6.3 Design of digital product passport for washing machines

This section covers the design process resulting in a DPP data structure for washing machines.

6.3.1 Digital product passport: Use cases

This subsection presents the use cases for an EEE manufacturer of washing machines, a retailer, a collection agent, and a repairer. The use cases illustrate the practical relevance of a DPP for washing machines. **Appendix E** contains the full description of the use cases.

Manufacturers

The first use case assumes that manufacturers produce long-lasting washing machines and offer additional life-extending services. The circular product design of washing machines incorporates design strategies supporting maintenance, repair, and upgradability. Manufacturers also apply remanufacturing strategies that encourage the reuse of washing machine parts to their production process. Affected by eco-friendly market demands and regulations, such as the Eco-design directive, manufacturers provide transparent information about their washing machines' sustainable, circular, social, technical, and economic performance. Using DPPs for washing machines contributes to realizing the manufacturers' circular ambitions and, as such, requires a rich supply of information across the EEE circular ecosystem. For example, using high-quality information on the circular performance of washing machines requires information on life cycle and repairability. Product and usage information allows the monitoring of the current status of washing machines during their product life cycle.

Retailers

The second use case focuses on a retailer selling new or reusable washing machines. This could be a retailer only selling new electronics, a second-hand white goods seller, or a thrift store selling second-hand washing machines. The use case assumes that the market demand for environmentally friendly and energy-efficient washing machines has increased significantly due to the transition to a circular economy. As a selling party, the retailer provides information to customers supporting them with knowledge of the product's characteristics and performance, its technical condition, reparability, sustainable and circular performance, life-extending repairs carried out, and the indicative residual life of the (reusable) washing machine. This information is recorded in a digital passport and its transparency triggers customers to purchase eco-friendly washing machines.

Collection agents

The third use case elaborates on the information needs of collection agents regarding a DPP for washing machines. The product and usage information in the DPP helps collectors objectively determine a washing machine's lifetime extension possibilities and, more specifically, an appropriate circular strategy. The use case assumes a configuration where collection agents and other consumer electronics play an essential role in the data-driven evaluation of the discarded machine. Collection agents objectify what a viable circular strategy would be, supported by product and usage information in a DPP. Product-specific, market-driven, technical, economic, and ecological assessment criteria are essential for this: collection agents record in the DPP relevant assessment results and passport which circular strategy they have selected for a washing machine.

Repairers

The fourth use case focuses on washing machine repairers affected by Right-to-Repair policies. The use case relates to repair facilities where repairers focus on diagnosing and repairing discarded washing machines with the aim of extending their lifetime. The repairer is assumed to aim to extend the service life in order to maximize the sustainability and circularity performance of the washing machine due to be repaired. The information in the DPP supports repairers and repairers in their diagnosis of the washing machines and carrying out repair and life-extending activities on discarded washing machines. Repairers record which revisions and repairs they performed in the passport. Influenced by digital technologies, the collectors' assessment of washing machines is shifting to one of continuous monitoring during the product life cycle. The continuous digital monitoring of washing machines calls for DPPs with a dynamic character.

The detailed four use cases clarify that several washing machine ecosystem stakeholders can benefit from the DPP to strengthen their role further. The data in the passport are suitable for collection agents when using direct applications related to the lifetime extension assessment of washing machines. The data that other ecosystem stakeholders add to the DPPs help collection agents to perform a comprehensive lifetime extension assessment of the collected washing machines.

6.3.2 Conceptualization of a digital product passport for washing machines

Table 6-2 provided the foundation for the data structure of the DPP. The study by Berger et al. (2022), focusing on the granular data structure of a digital battery passport, has proven valuable for the DPP data structure for washing machines. The assessment categories in **Table 6-2** can be linked to the defined information categories in the DPP (see **Figure 6-3**). The DPP concept contains four information categories: Washing machine product, Value chain actors, Diagnostic, maintenance and performance, and Sustainability and circularity. The data in these information categories makes it possible to make informed decisions regarding the lifetime extension of washing machines. In consultation with the client, the choice was made not to include the "Market demand" assessment category in **Table 6-2** in the DPP because the character of this category is insufficiently in line with the product, technical and environmental content of a DPP.

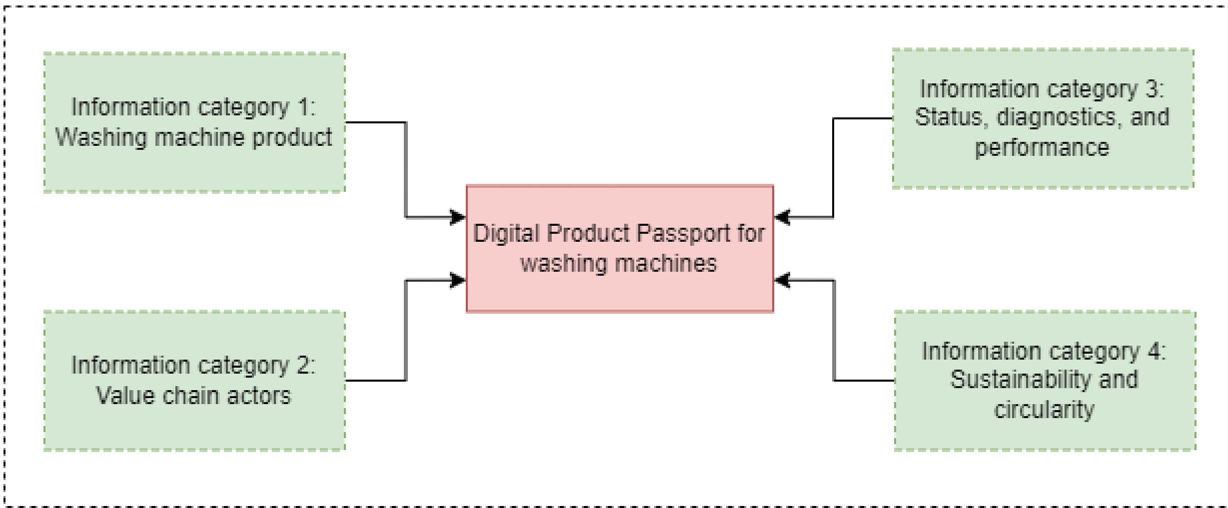


Figure 6-3: General structure of DPP for washing machines

Information category Washing machine product

The first information category provides decision-makers with information on product identification, supporting information, product properties, and performance according to the specifications of the washing machine manufacturer. The product identification of a washing machine refers to data properties such as the brand, the product type or model, the EAN number, and the serial number. The name of such identification data may differ per washing machine. Correct identification of an individual device is crucial for value chain actors because it provides access to relevant product data in databases, such as product specifications, repair manuals, and part numbers. The product support information refers to the documents that provide insight into the product features of a washing machine and support the technical repair process. Examples are: product manuals, exploded views, an overview of washing programs, failure diagnostics codes, and circuit diagrams. The physical product features relate to the product specifications, such as device images, dimensions, fill weight, material quality, washing programs, washing functions, and specific product properties. This information provides an actor insight into the product properties of a washing machine. The performance category of a washing machine quantifies various performance indicators, such as energy and water consumption, noise level, and washing result. The list price of a washing machine is also part of a DPP to give actors an impression of the product quality of a washing machine.

Information category Value chain actors

The second information category, Value chain actors, provides transparency into value chain actors who have interacted with a device at any point during the product life cycle of a washing machine, e.g., during manufacture, sale, use, disposal, collection, or repair. The classification of this information category is partly based on the study by Berger et al. (2022). The information on value chain actors covers general actor information, log data, and chain of custody. The general actor information contributes to the identification of involved value chain actors, their role in the value chain, their status, and their location. Log data refers to the collection and storage of data during the product life cycle of a washing machine. Such historical records give actors insight into the data, status, and activities carried out by different value chain actors during a washing machine's lifecycle. This might include the production date, repairs performed, upgrades performed, error messages, transport movements, and the location of the collection point where a washing machine has been discarded. Information concerning the chain of custody clarifies the actor's responsibilities, e.g., regarding the physical washing machine itself and its sustainability and circularity performance (Berger et al., 2022). This information clarifies which value chain actor has been responsible for a washing machine product or part during a defined period.

Information category Status, diagnostics, and performance

The third information category, Status, diagnostics, and performance, is relevant for determining whether a washing machine can still be used for a potential second life phase after its discarding. This information category responds directly to the need for product and usage information to objectify whether extending the lifetime is feasible or not, based on technical parameters. Information on the washing machine's health, such as its physical condition, failure diagnostics, usage history, and residual lifetime is crucial. Information about maintenance history provides insight into the maintenance and repair activities that have taken place during a washing machine's product life cycle. The washing machine's performance may decrease during a life cycle. Information in the DPP therefore provides insight into the current performance of a washing machine, including its residual lifetime and energy and water consumption.

Information category Sustainability and circularity

The fourth information category, Sustainability and circularity, is becoming increasingly relevant for value chain actors in the transition to a circular economy. Value chain actors are increasingly requested to objectify their sustainable and circular performance. Therefore, the information in this category pertains to the sustainability and circularity-related properties of washing machines. Life cycle analysis methods and calculations play a significant role in the quantification of this information (Alejandre et al., 2022). The definition of sustainability is "the balanced and systemic integration of intra and intergenerational economic, social, and environmental performance" (Geissdoerfer et al., 2017, p. 759). The emphasis here, then, is on how life support systems meet the current generation's needs without compromising the needs of future generations. A circular economy, on the other hand, is a "regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops" (Geissdoerfer et al., 2017, p. 759). The difference between sustainability and circularity is that sustainability focuses on people, the planet, and the economy and is more open-ended. Circularity is part of the concept of sustainability and focuses on the cycles of raw materials. Due to the focus of national and European in their circular economy and sustainability policies (Krämer, 2020; Ministerie Infrastructuur & Waterstaat, 2022; Ministerie van Buitenlandse Zaken, 2023), both issues are addressed in the DPP for washing machines because the circular economy policies. The division into information categories is from Berger et al. (2022).

Information about sustainability-related properties in the digital passport provides insight into a product's environmental and social impact (Berger et al., 2022). This environmental impact information relates to categories of impact, performance indicators, indicator calculation methods, inventory data, and impact assessment methods. The social impact can theoretically be operationalized in information related to working condition indicators (such as safety). However, due to the focus on lifetime extension, this component receives little attention in the DPP. The information on circularity-related properties relates to circularity performance and the product design-related properties of washing machines. Circularity performance can be operationalized in a similar way to information about sustainability properties. The underlying information relates to resource efficiency, materials used, increase in durability, and the useful lifetime of washing machines (Berger et al., 2022). Circular performance assessments and provision for underlying information play a central role in this (Sassanelli et al., 2019). The information on the product design of washing machines provides insight into the applied circular product design strategy and the reparability of a product.

For the purposes of feedback, the first draft of a DPP was presented to a circular economy and waste management expert. **Appendix F** summarizes their feedback on the DPP. The experts stated that the initial level classification of the information categories in the product passport was arbitrary. The expert also suggested that not all information should be registered in the DPP, but that information should be part of the assessment process, for example, information concerning regulations and the economic feasibility of lifetime extension. The expert also indicated that the information needs of the EEE stakeholders in the use cases should be fulfilled by the information in the passport. Another feedback point was that time-dependent data, such as the cost of parts, are not included the passport. The expert also indicated that restrictions on data availability and accessibility are essential. Future implementation of the DPP implies that differentiation of data is required, such as level of detail, access rights, editing rights, rights to add information, and data confidentiality. In the future, it would be desirable to facilitate connections to material passports. To increase the lifetime of washing machine parts, the identification numbers of these parts must be addressed in the passport. The client also indicated that the Sustainability and circularity information category is highly relevant due to increasing sustainability requirements. However, lifecycle analyses require complex calculation methods and far-reaching insights into the process activities in the EEE value chain. Thus, data in the passport concerning energy and water consumption has priority.

6.4 Validation results of use cases and digital product passport

This section presents the validation results of the respondents to whom the use cases and a DPP were submitted for feedback. **Appendix G** details the validation results.

6.4.1 Manufacturer use case

The respondent indicated that he recognized the changing role of washing machine manufacturers in the use case. In line with compliance and retailer demand, producers increasingly provide detailed product information. According to the respondent, emphasis should be placed on data on hardware and software applications and production and logistics specifications in the use case. Information about washing machine parts and inventory systems is becoming increasingly important and, therefore, requires corresponding data in the DPP. Return flows are also becoming increasingly relevant for producers and require optimum provision of information. Producers feel increasing pressure to justify their sustainability efforts. The transition to service-oriented business models at the washing machine manufacturer stimulates the idea of lifetime extension and a product life cycle approach. However, the business models place high demands on the producers' information provision.

According to the respondent, the DPP should have a dynamic character enabled by of Internet-of-Things applications. Digital technologies in washing machines enable data generation, real-time monitoring, and predictive maintenance. The respondent indicated that he considers information category 1, Washing machine product, and information category 3, Diagnostics, maintenance, and performance as a "must have" priority. According to the respondent, the product information in category 1 is dependent on the information in category 3. According to the respondent, information category 2, Value chain actors, tallies with the intended product life cycle approach but requires significant systemic effort on the part of actors across the EEE value chain. Producers must be able to clarify the life-extending activities that can contribute to footprint reduction and objectifying their sustainability claims. At the same time, this requires many data across the EEE value chain. Therefore, the respondent prioritized information categories two and four as "could have"; this information would be nice to have for the manufacturer but is not essential. According to the respondent, the priority in building a DPP is primarily one of product, usage, and product recovery information.

6.4.2 Retailer use case

Validation of the retailers' use case was set up with a commercial outlet and a thrift store retailer selling washing machines. Both respondents recognized that their role is likely to change in coming years, as a result of the increase in environmental awareness on the part of their customers. Affected by rising energy prices, environmental aspects, and economic factors, customers want to make well-considered purchase decisions. According to the thrift store respondent, the use case should emphasize that information in DPPs must be understandable to customers, e.g., in pictograms or rankings. The respondents acknowledged the social issues outlined in the use case but stated that environmental issues are more prevalent in most customers' purchasing decisions. The information needs in the use case ensure that respondents can fulfill their role as retailers in a circular economy. The far-reaching transparency of a broad information set supports the retailer in sales and customer consultation. However, the commercial retailer contested that future customers' economic situations still guide their purchasing decisions.

The detailed information categories in the DPP are recognizable to both respondents. Information Category 1 is prioritized as a "Must have" by the commercial and thrift store retailer, although the commercial retailer indicated that much of the information in this category can be found in the databases of washing machine manufacturers. Information category 2 was prioritized by the commercial retailer as a "Won't have" and as a "Should have" by the thrift store retailer. The commercial retailer stressed that from an economic perspective, the DPP is especially interesting for devices with a high economic value. Recording all activities in this information category might take a disproportionate amount of time. Information category 3 was a "Must have" priority for the thrift store retailer in line with their desire to provide full transparency in the future into the diagnostics and repair activities performed to give customers confidence in the product quality of a reusable washing machine. The commercial retailer prioritized this information category as "Should have." Because this retailer only sells new washing machines, this information is certainly relevant but not the highest priority. Both respondents indicated that category four information is becoming increasingly important when advising customers who want to buy an environmentally friendly washing machine. The commercial retailer prioritized this information as "Could have" and the thrift store retailer as "Should have." Unlike retailers, sustainability is embedded into the mission of thrift stores.

6.4.3 Collection agent use case

The validation session with the collection agent clarified that his future role would be upgraded to the return evaluation of collected consumer electronics. However, the respondent pointed that this role change is only possible if sufficient information is provided; an adequate provision of information enables informed decision-making concerning lifetime extension. The respondent indicated that this will only be possible if the underlying DPP systems and processes are automated. Automated information systems should instruct collectors' employees on what specific actions they must perform. The respondent emphasized that the collection and lifetime extension assessment system should have a dynamic character based on the digital technologies in washing machines and their unique product specifications. In future, each washing machine will follow a unique process route. The respondent indicated that the broad provision of information in the use case and the DPP aligns with the ambition to transform themselves from a collection agent into an assessment center. The information needs in the use case address the current problem that product, product recovery, and usage information are not available. For example, the availability of product support information contributes to rapid diagnosis and repair. The respondent appreciated the fact that the use case, in addition to product and product repair information, also pays attention to ecological and social impact information. The respondent commented that the use case should mention the relevance of identification, the harvesting of parts, and the relationship with a parts inventory system. New and harvested parts play a decisive role in extending the life of washing machines.

The respondent indicated that collection agents require most of the data in the DPP for lifetime extension assessment purposes. The four detailed information categories in the DPP sufficiently cover the information required to assess collected washing machines. The respondent prioritized information category 1 as a "Must have." Product identification and support information in information category 1, at the level of product and parts, are crucial for collection agents. However, according to the respondent, the detailed product specifications in the DPP are less relevant for collection agents.

Information category 2 was helpful to the respondent because this information in the DPP contributes to the transparency and traceability of the EEE value chain. Such transparency supports collection agents in their lifetime extension assessments. The respondent prioritized information category 2 as a "Should-have," indicating that this information category bridges the current asymmetry of information in the EEE value chain. However, far-reaching automation of the entire system is still required to realize this ambition. In this DPP information category, the respondent indicated that information concerning regulations is currently lacking.

The respondent prioritized information category 3 of the DPP as a "Must-have." The elaborated information categories and data properties match the information needs of the respondent. According to the respondent, digital technologies in washing machines will enable remote assessment. According to the respondent, it is also relevant to include information about the performance of the components.

Information category 4 of the DPP was prioritized by the respondent as a "Could have." Sustainability and circularity are becoming increasingly important topics, but the respondent states that the focus should initially be on energy and water consumption. The respondent values information on a washing machines' repairability. Future quantification of repairability in the French Repair Index is valuable in the lifetime extension assessment.

6.4.4 Repairer use case

Both respondents indicated that the exact usage situation of the repairer is in line with developments in the washing machine ecosystem. The application of digital technologies in washing machines is analyzed in a data-driven manner of diagnosis and repair. The commercial retailer revealed that they often retrieve washing machine product information from manufacturers' databases. However, these databases are only accessible to certified service providers. The thrift store repairer indicated that the outlined developments in the use case solve the product’s current defect, repair support, and usage information. The respondent from the thrift store also suggested that the role of maintenance in the use case should be emphasized due to its positive effect on lifetime extension. The commercial repairer commented that repair costs should be proportional to the initial purchase price. In the use case, the information needs of a repairer concerning expected repair costs should be addressed.

Both respondents indicated that information categories 1 and 3 are "Must have" priorities because this DPP information is conditional on repair. Product-specific information in category one is the foundation of the repair process. The thrift store respondent stated that details of manual test results and washing machine spare parts should be added to the information category. The commercial repairer commented that information category 3 should not contain too much information so that the DPP does not become unnecessarily complicated.
Although information categories 2 and 4 in the DPP are relevant to both respondents, they both initially gave them less priority. The commercial repairer prioritizes information category 2 as "Could have", while the thrift store prioritizes this information as "Should have." The information about a washing machine's maintenance, use, and repair history supports them in the repair process. Both respondents agreed that the relevance of information category 4 is increasing, but compared to other information categories, this information is less relevant for repairers. According to the respondents, sustainability and circularity information should make up a disproportionately large share of the DPP and are especially relevant for a retailer. However, according to the thrift store repairer, information on product design and the repairability of washing machines is valuable. The respondents prioritized information in category four as "Could have."

Table 6-3 summarizes the respondents' priorities for the information categories in the DPP. The table reveals that respondents attached most value to information categories 1 and 3. Although they see the relevance of information categories 2 and 4, they currently regard these as secondary or tertiary priorities because of the extensive data they require in a circular washing ecosystem.

		Information categories			
Use case	Respondent	1. Washing machine product	2. Value chain actors	3. Diagnostics, maintenance and performance	4. Sustainability and circularity
Manufacturer	Respondent 1 (manufacturer)	Must have	Could have	Must have	Could have
Retailer	Respondent 2 (thrift store retailer)	Must have	Could have	Must have	Should have
	Respondent 3 (commercial retailer)	Must have	Won’t have	Should have	Could have
Repairer	Respondent 2 (thrift store repairer)	Must have	Should have	Must have	Could have
	Respondent 3 (commercial repairer)	Must have	Could have	Must have	Could have
Collector	Respondent 2 (thrift store collector)	Must have	Should have	Must have	Could have

Table 6-3: Prioritization of information categories

6.5 Feedback digital product passport development

The validations of the use cases and related DPP information categories indicated that the DPP for washing machines is valued as a helpful decision-making instrument for various stakeholders in the washing machine ecosystem. Currently, commercial value chain actors, such as washing machine manufacturers and retailers, already have access to data supporting them in lifetime extension issues. Much of the information and data described in the DPP are logged in manufacturers' databases. For non-certified parties, such as thrift stores, the DPP concept contributes to the high-quality collection, repair, and sale of collected washing machines. Influenced by the prospect of future DPPs and a significant increase in the number of digital washing machines in circulation, both respondents indicated that system automation and information sharing across the washing machine ecosystem are necessary.

Furthermore, respondents' feedback has enabled the DPP to be refined. The final version of the DPP data structure is outlined in **Section 6.6**. In the short term, availability of the information in categories 1 and 3 is relevant for the interviewed respondents. In the longer term, the relevance of information categories 2 and 4, value chain actors and sustainability information, will gradually increase.

Based on respondents' feedback in information category 1, the subcategory "Product support information" has been supplemented with data properties on the tools required for repair, service manuals, and software and hardware versions of a washing machine. Category 2 information on value chain actors will be maintained. The existing data properties regarding "compliance with regulations" is relevant to demonstrating that value chain actors comply with legal requirements. Under the sub-information category, Log data, the events of a stakeholder are logged during product life cycle. One respondent's request to include data on the producer's or retailer's initial list price can be incorporated into this information category.

Respondents stated that, because of the potential of digital technologies, the DPP for washing machines should have a dynamic character. A dynamic character does not necessarily lead to a substantive adjustment of the DPP's content but is associated with the DPP's usage frequency. Specific steps which are still performed manually, such as determining the product identity and visual checks using photo scans, can also be automated. The dynamic character of the DPP becomes evident in information category 2 because the activities of value chain actors are continuously monitored. In information category 3, visual inspection photographs are specified for the sub-category Visual inspection in the data properties.

Furthermore, the information in category 3, Status, diagnostics, and performance, means that the one-off assessment of a washing machine leads to continuous monitoring of its health. To reflect this, the phraseology has been changed from the previous information category, Product usage history, to Product usage status. The interviewed respondents indicated several times that the DPP should pay explicit attention to key washing machine spare parts. However, the technical testing of components already forms part of the sub-category Failure diagnostics. The sub-category Device settings was part of the "Product usage history" category in the previous DPP version. As this was factually incorrect, the final version includes information about device settings in the sub-category, Maintenance and repair history.

Finally, the conceptualization of information category 4, Sustainability and circularity, in the DPP has remained unchanged after respondents' feedback.

6.6 Final data structure of digital product passport

Based on feedback from circular economy experts, version 2 of the DPP for washing machines has been completed. For each information category, a classification scheme has been designed to represent information and data properties in the digital passport. Its original division into levels has been removed and replaced by a distinction into information categories and data properties. **Figure 6-4** shows information for the washing machine product category. Product identification has remained unchanged. The complexity here is that the identity codes of different brands of washing machines differ significantly. To guarantee traceability of a washing machine product, product identification data provide insight into production and logistics data. The sub-information category, Product information, is supplemented with repairability information about parts, references to support services, failure codes, instructions for reconditioning, and 3D printing instructions (Bracquené et al., 2018). This subcategory also contains photographs of the devices and information on product warranty. The information and data properties for product characteristics and the underlying physical properties and performance of washing machines have remained unchanged. Specific information on the product quality of a washing machine's parts and materials is part of a related materials passport which can be merged with the DPP for washing machines.

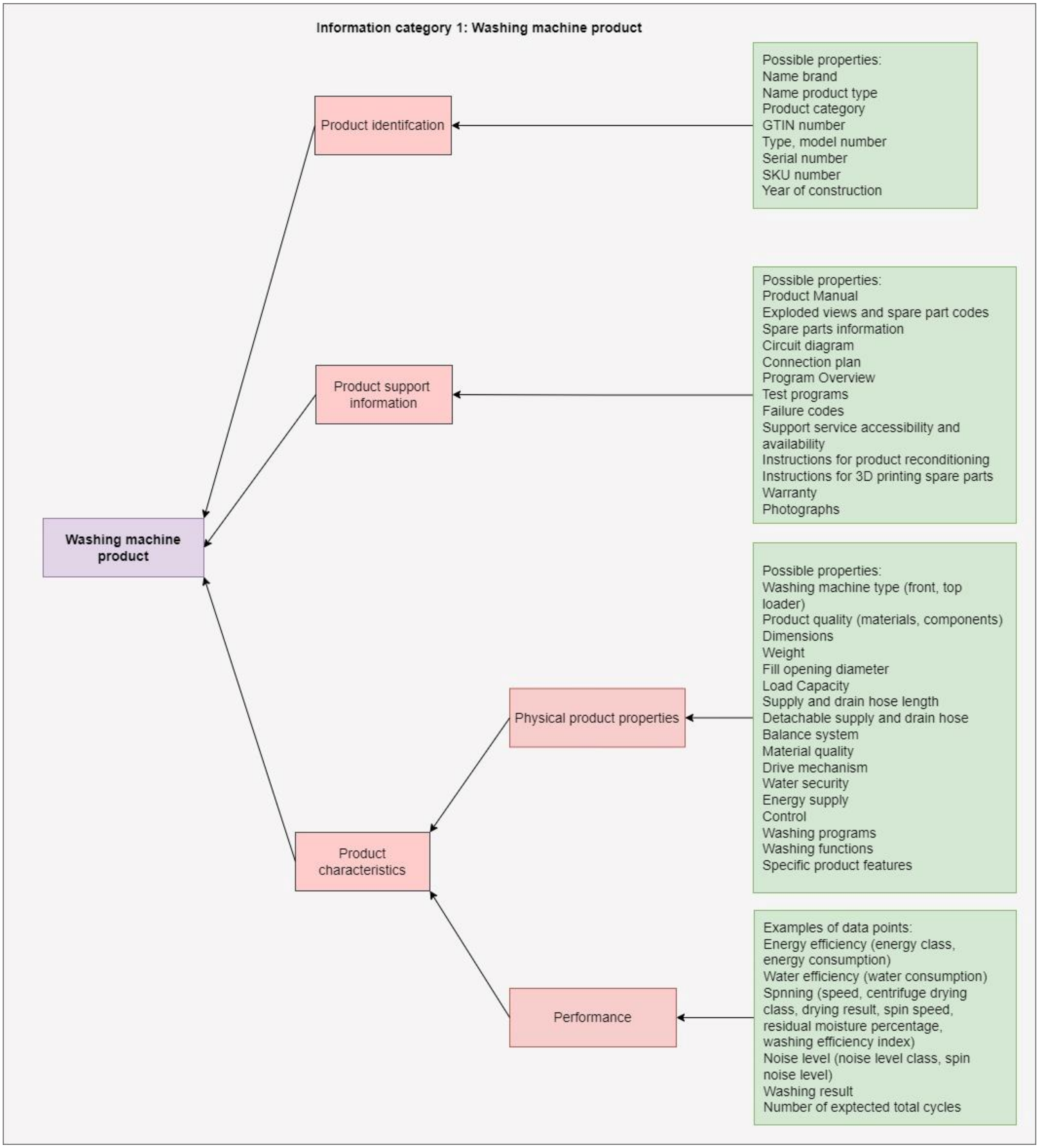


Figure 6-4: Information category Washing machine product

Figure 6-5 presents the Value chain actors information category. This information has remained virtually the same. However, GDPR restrictions have meant that information on the value chain actors themselves is generalized.

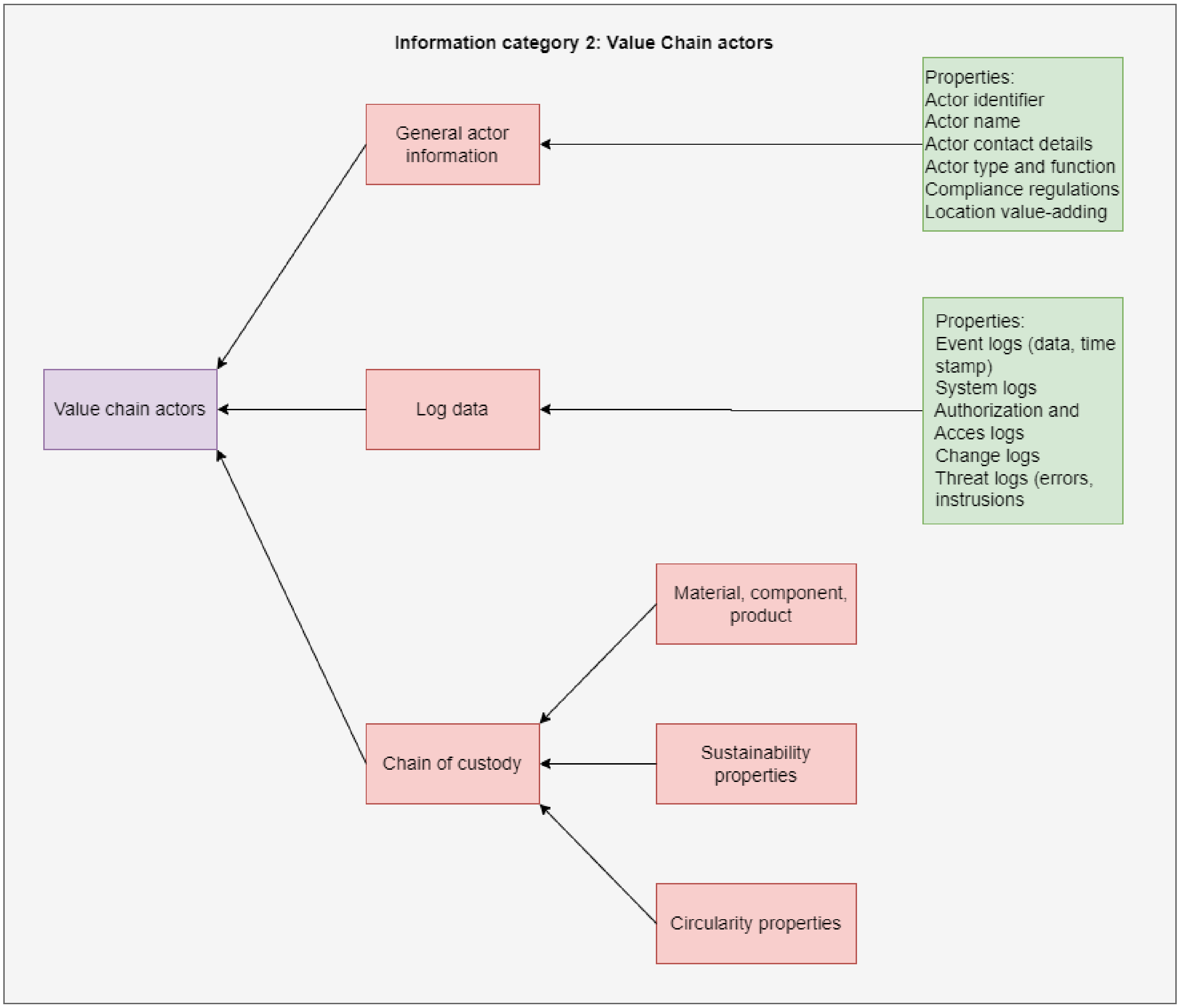


Figure 6-5: Information category Value chain actors

Figure 6-6 presents the Diagnostics, maintenance, and performance information category in the DPP. The information in this category has been modified in some areas. A distinction has been made between product and usage information. The physical condition of a device relates to visually observable aspects of its health, such as rust, dents, and completeness. A new information category, Technical Assessment of the device, has been added. This category contains information about failure diagnostics based on information and test results from functional and safety tests (Bovea et al., 2016). Failure codes, fault memory data, and test results are essential data properties. Again, due to the potential for digital technologies in washing machines, such data will be able to be generated automatically in the future. The sub-information category, Product usage, is relevant when assessing lifetime extension because it provides insight into how a washing machine has been used. A distinction has been made between usage intensity, usage marks, delivered performance, and device settings. Usage intensity can be operationalized in the number of washing machine cycles performed. The ratio between usage intensity and capacity influences the residual life of a washing machine. Information on usage marks, such as rust and corrosion, can be generated by performing standardized checks. Information on the delivered performance provides insight into the extent to which the performance of a washing machine differs from the initial performance specifications, e.g., its spinning and drying results. Information on device settings provides insight into a washing machine's software version and its general settings. The sub-information category, Maintenance history, has been expanded to include repair history. The relationship with the Value chain actors information category is relevant because this information provides insight into who may have repaired a washing machine and who is qualified to do so.

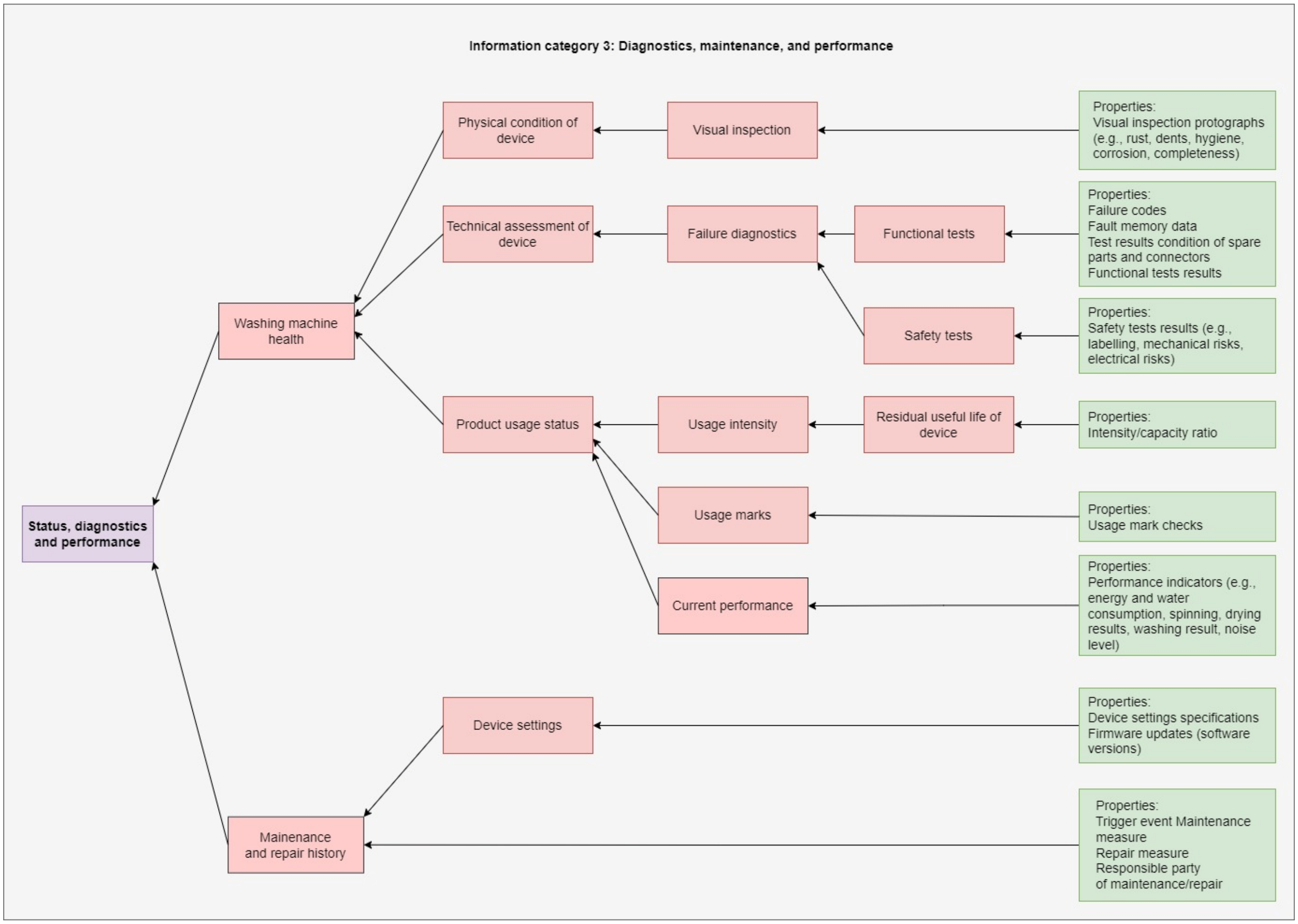


Figure 6-6: Information category Status, diagnostics, and performance

The fourth information category, Sustainability and circularity, has remained virtually unchanged (see **Figure 6-7**). The complexity of this information category derives from the fact that the intended transparency into a washing machine's sustainability and circularity aspects requires a lot of information as well as data on life cycle analysis aspects. This passport information category makes it possible to calculate, at several moments in a product's life cycle, whether lifetime extension is desirable from a sustainable and circular perspective (Alejandre et al., 2022). Possible sustainability claims by manufacturers, product repairability, and the environmental impact of extending the lifetime can thereby be objectified. In addition to the calculated outcomes of such a life cycle analysis, it is crucial to provide users with transparency into the underlying methodological assumptions behind such a calculation. The sub-information category, Circular product design-related properties, contains information on a washing machine manufacturer's applied circular product design strategies. This includes Design for Durability, Design for Easy Maintenance, Design for Repair, Design for Upgradability, Design for Refurbishment, or Design for Product-Service Systems (Moreno et al., 2016). Such design factors affect a washing machine’s repairability. Therefore, repairability data properties are also defined in the DPP. Manufacturers quantify the repairability of a washing machine according to repairability criteria for energy-related products (Bracquené et al., 2018). Examples of repairability data properties are ease of disassembly and ease of resetting.

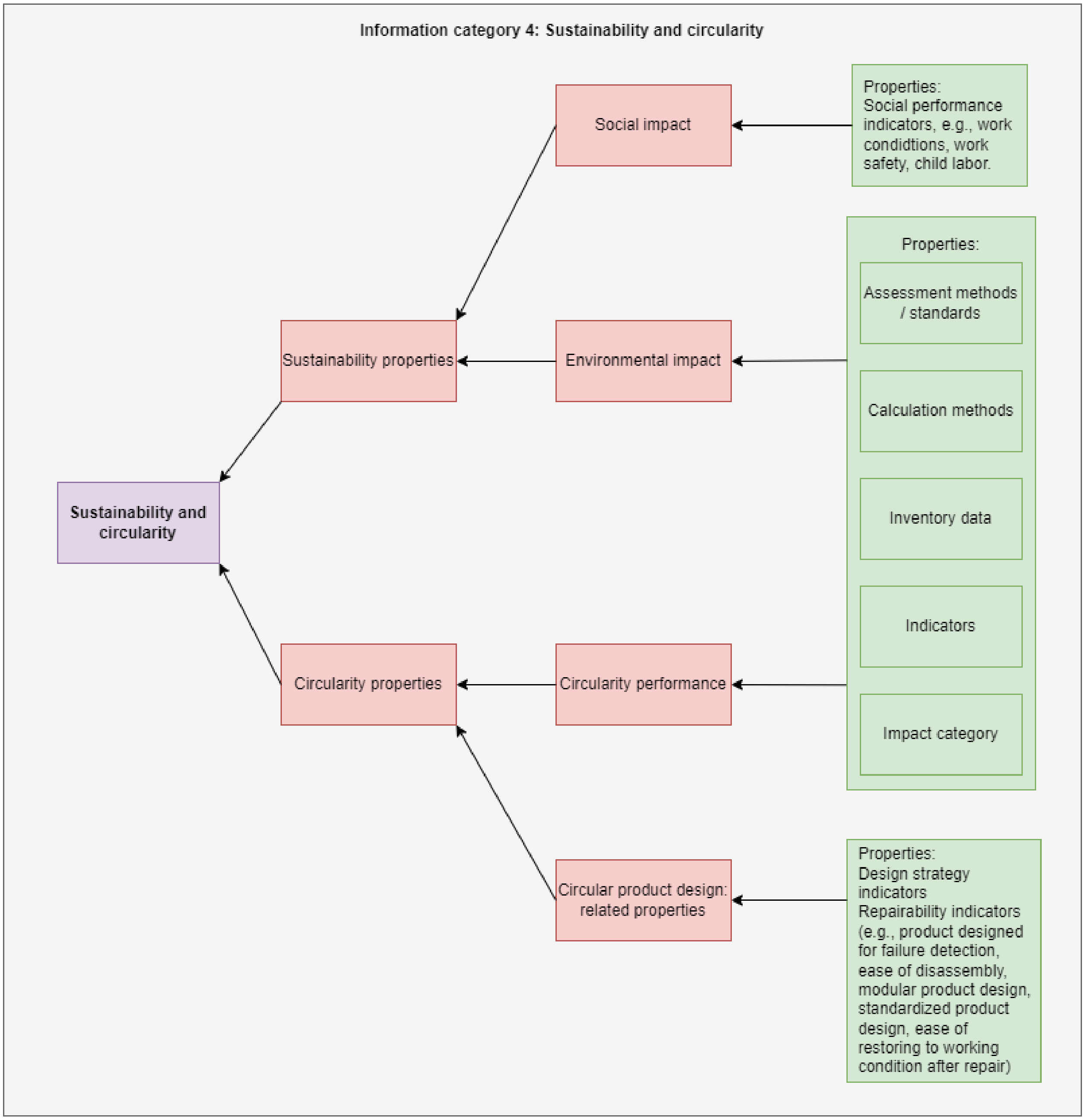


Figure 6-7: Information category Sustainability and circularity properties

6.7 Process diagram: data-driven lifetime extension assessment

Section 6.6 detailed the information categories and data properties in DPPs for washing machines. The availability of information in the DPP allows for a comprehensive, objectified, and data-driven lifetime extension assessment of collected washing machines by collection agents. To clarify the role of the DPP in the lifetime extension assessment of collected washing machines, a process diagram for the 2030 scenario has been developed. This is based on the following assumptions:

- By 2030, most washing machines will incorporate digital technologies such as Internet-of-Things.
- All data in the DPP are assumed to be available and accessible.

- The information systems in the EEE value chain are highly automated, and information sharing across value chain actors is commonplace.
- Digital technologies allow for the allocation of a washing machine's generated data to the cloud. Every value chain actor has access to the data in the DPP (differentiation in levels of detail is still possible)
- Discarded washing machines are, to a large extent, still collected and assessed for lifetime extension by collection agents.
- When designing the process diagram, it was assumed that the intake of washing machines and their lifetime extension assessment at a collection agent take place as a one-off assessment. Despite datafication of the EEE value chain, the lifetime extension assessment also requires manual visual inspections e.g., to assess the inside of a washing machine, to confirm previous data-driven diagnoses, and to identify root causes. However, future digital technologies potentially allow for remote assessment (e.g., visual inspection at collection centers). Such a situation is not assumed in the process diagram.
- Parallel to a data-driven assessment of washing machines, and as part of a decision-support system, an assessment component is available to check the data properties values in the DPP against established standards. In this explorative projection, these standards have not been specified.

Figure 6-8 shows the process diagram where DPP data supports the collected washing machines' lifetime extension assessment process. The assessment of collected washing machines is based on a 'funneling method', where in the process by testing a group of assessment criteria, washing machines drop out step by step. Such an approach enables the early exclusion of washing machines that are not eligible for lifetime extension. Due to time efficiency considerations, a large part of the assessment in the first phases is data-driven. If a washing machine meets the requirements of the generic assessment factors, time-consuming manual visual inspections are performed.

The diagram in **Figure 6-8** includes six process steps, data values in the DPP, and norms for each value in a DSS. In step 1, a collected washing machine arrives at a collector and is registered. By scanning a machine-readable optical label, all the washing machine's identification data are extracted from the DPP. In step 2, the lifetime extension assessment of the washing machine starts. At the product level, a washing machine is assessed for generic factors. These generic factors relate to product characteristics, technical performance, market demand, and ecological impact. The assessment is based on the information in the DPP, whereupon data property values are compared to the standards in the DSS. If a washing machine does not meet these standards, it is not eligible for lifetime extension. In the case of acceptable values, the washing machine is diagnosed in step 3. This diagnosis focuses on the washing machine's status and health. During the diagnosis, the washing machine is assessed for physical condition, technical condition, product usage status, and maintenance and repair history. If the data properties values in the DPP are acceptable, a washing machine is visually inspected in step 4, e.g., for completeness, rust, dents, and usage marks. This process step can be partially automated, for example, using photograph analysis. However, an inspection of the washing machine's insides still requires a technical employee's involvement. Data are extracted from the DPP, and the visual check results are then registered in the DPP.

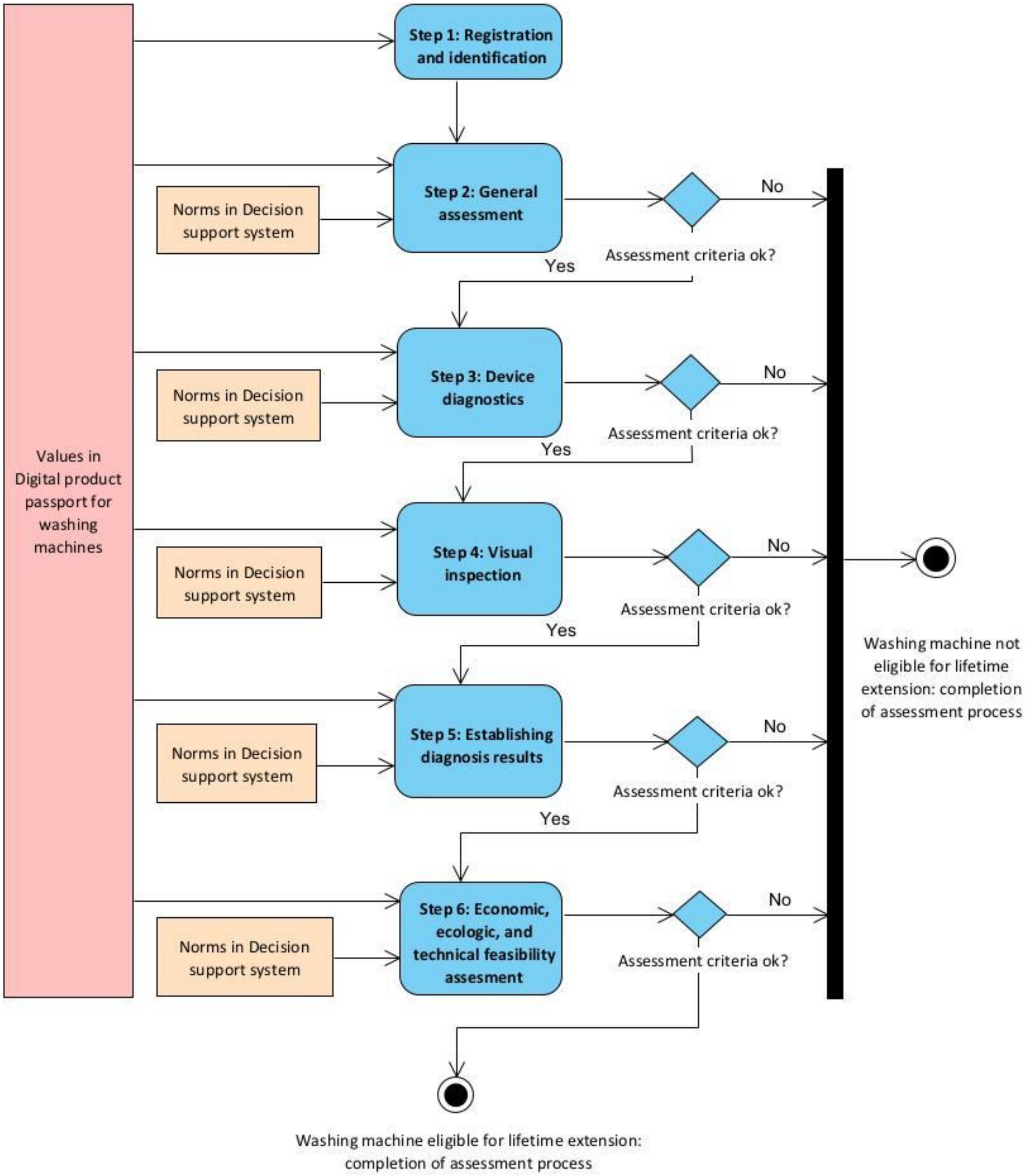


Figure 6-8: Process diagram: lifetime extension assessment 2030

In the case of acceptable visual inspection results, in step 5 a final diagnosis of the washing machine is performed based on the assessment results in steps 3 and 4. In this diagnosis, the actual diagnosis based on the current status of the washing machine, as recorded in the DPP, is determined. Based on a 'diagnosis-recipe' approach, the DSS determines which possible repair activities must take place to extend a device's lifetime. Based on the estimated repair activities, the economic, technical, and ecological feasibility of extending the lifetime is tested. If this data-driven assessment meets the standards set in the DSS, the assessed washing machine qualifies for a lifetime extension. The feasibility test results in this process step are recorded in the DPP. If a washing machine is not eligible for lifetime extension during these process steps, the lifetime extension assessment component suggests whether parts or materials can be harvested from the washing machine. However, this check falls without the scope of the system.

During the assessment process, data are extracted from the DPP to determine the values of relevant assessment criteria. The required data for each assessment criterion refers to an information category, a specific sub-category, or a data property in the DPP. As mentioned in **Section 6.2**, the DPP's relevant information and data sources are detailed in **Appendix D**. **Table 6-4** provides insight into which data from the DPP is used for each phase in the assessment process. This table reveals that data from all information categories in the DPP are used during the assessment of washing machines in various process phases. An exception to this is information on social impact. This assessment criterion is not part of the scope of the lifetime extension assessment. Furthermore, while in **Table 6-2**, the professionalism of value chain actors is an assessment criterion, this criterion is part of process step 3 (device diagnostics) in **Figure 6-8**. The assessment criterion, Environmental performance, is part of the general assessment in step 2 in which a washing machine is assessed for energy and water consumption. **Table 6-4** also indicates that the Economic feasibility criterion cannot be determined solely with the information in the DPP. Such information requires additional digital instruments and calculation methods aimed at objectifying the economic feasibility of washing machine lifetime extension is outside the scope of the DPP for washing machines.

Process phase	Assessment criteria	Information category 1: Washing machine product	Information category 2: Value chain actors	Information category 3: Status, diagnostics, and performance	Information category 4: Sustainability and circularity
1. Registration and identification	-	Product identification	General actor information Log data	-	-
2. General assessment	Product quality	Physical product properties (product quality of materials and components, Materials passport)	Value chain actors: general actor information, log data, chain of custody	-	-
	Physical product properties (expected market demand)	Product identification Physical product properties (e.g., type, load capacity, drive mechanism)	-	-	-
	(Original) product performance specifications	Performance (e.g., energy and water consumption, washing performance)	-	-	-
	Circular product design strategies	-	-	-	Circular product design related properties
	Product repairability	Product support information	-	-	Circular product design related properties (repairability)
3. Device diagnostics	Washing machine health	Product support information	Value chain actors: general actor information, log data	Washing machine health Maintenance and repair history	-
4. Visual inspection	Washing machine health	Product support information	-	Washing machine health (visual inspection, failure diagnostics, usage marks)	-
5. Establishing diagnosis results	-	-	-	-	-
6. Economic, ecological, and technical feasibility	Environmental aspects	Product characteristics, performance (energy and water consumption)	-	-	Sustainability properties Circularity properties
	Technical feasibility	Product support information (e.g., spare part codes)	-	-	Circular product design related properties (repairability)

Table 6-4: DPP application in lifetime extension assessment process

6.8 Summary and conclusion

This chapter documented the DPPs design and development process, and the artifacts which allow for data-driven assessment of collected washing machines. Relevant assessment criteria can be traced back to product characteristics, current washing machine health, the professionalism of value chain actors, environmental aspects, and market demands. The use cases and DPP validation process revealed that respondents especially value data on the product characteristics and current condition of washing machines. Respondents confirmed the added value of data on value chain actors and environmental aspects but prioritized these only as a secondary information need. One complexity of the sustainable and circular data properties is that they require additional instruments, such as calculation and assessment methods. Another complexity is that circular ecosystem stakeholders should permit data availability and accessibility to other relevant EEE stakeholders. According to the respondents, product-related, technical, and repairability aspects are decisive in the lifetime extension assessment of washing machines. Respondents also indicated that, in future, in addition to the current focus on product, lifetime extension assessment should also concentrate on extending the lifetime of components. A detailed generic process diagram illustrates how the data in a DPP are applied to the lifetime extension assessment of a washing machine.

The vulnerability of the DPP is that it is currently unclear whether collection agents will provide access to the necessary data in future to be able to carry out the detailed data-driven assessment process. To support collection agents in their lifetime extension assessment of collected washing machines in the short term, and taking into account the current asymmetry in the information, an assessment component has been developed in **Chapter 7** that offers a starting point from which to work gradually towards DPP-driven assessment.

7 Lifetime extension assessment component current situation

In this chapter, as part of the information system for collection agents, the design of a decision process for a lifetime extension assessment component has been developed for use in the current situation. The lifetime extension assessment component is the partial implementation of a lifetime extension assessment process which can be used in the current circumstances and has the potential to evolve for use in future situations. This chapter outlines the system development process of the assessment component. Three versions were developed during the design process of the assessment component. **Section 7.1** describes the design research approach underlying the system development process. **Sections 7.2**, **7.3**, and **7.4** present the design and validation of the assessment component's first, second, and third version, respectively. **Section 7.5** outlines a migration plan that offers collection agents practical guidance on implementing the assessment component. **Section 7.6** summarizes and concludes the chapter.

7.1 Design research approach

As stated in the problem investigation in **Chapter 2**, the limited data accessibility in the current situation has far-reaching consequences for collection agents' ability to fulfill their circular role. The data-driven assessment component developed in **Chapter 6** shows how data accessibility and availability could contribute to collecting agents' objectification of the lifetime extension assessment.
However, in the current situation, collection agents often do not have the desired data to perform the lifetime extension assessment. Such data restrictions have consequences for the system development process of the assessment component. According to a cyclic-iterative process, the assessment component was developed. For each assessment component version, the design research methods used are explained in the following subsections.

7.1.1 Design and validation of assessment component prototype version 1

In the first step of the development process, the assessment criteria and the associated primary and secondary data indicators in **Appendix D** were critically reviewed again. Those assessment criteria that can be checked in the current situation, because primary or secondary data indicators and properties are accessible, have been selected. During this exploratory analysis, it became clear that the limited data availability means that selected assessment criteria are extensively tested against secondary data indicators and properties.

A draft version of the assessment component was presented to the client and the head of the technical workshop of a thrift store during two separate working sessions. During these working sessions, the design principles were defined, a discussion was held about which assessment criteria, according to the respondents, have the most significant predictive value with regard to the lifetime extension of a collected washing machine, which data are needed to check each assessment criterion, what appropriate acceptance standards are for each criterion and what is a logical order of the assessment criteria. Another discussion point was related to the organizational restrictions that should be considered, such as assessment time and the competencies of employees of collection agents. Based on feedback from the respondents, a first version of the assessment component for the current situation has been developed.

In December 2022, the lifetime extension assessment component was validated at a collection point in the southern Netherlands. The majority of the white goods collected consists of discarded washing machines. Every day, collected washing machines arrive by truck at the collection point. The discarded white goods are collected across a large region and arrive at the collection point via various reverse logistics channels. The number of washing machines collected by retailers is the most extensive channel in this respect. The product quality of these collected washing machines is higher compared to washing machines collected at a municipal collection center.

The purpose of the validation was to determine:

- To what extent are the selected criteria in the assessment component appropriate for estimating whether lifetime extension is possible?
- To what extent does the laymen and the expert following the same decision-making process reach the same conclusion?
- Which checks does an expert perform when applying his own implicit assessment method?
- To what extent does the outcome of an expert's implicit assessment method differ from the outcome of the applied lifetime extension assessment component?

In total 41 washing machines were assessed. Fifteen of these machines arrived shortly before the validation started. The other 26 washing machines were randomly selected by the expert, aiming for a sample spread across the various washing machine brands. One obstacle was the physical accessibility of the washing machines in the warehouse. **Figure 7-1** presents the research procedure that was followed.

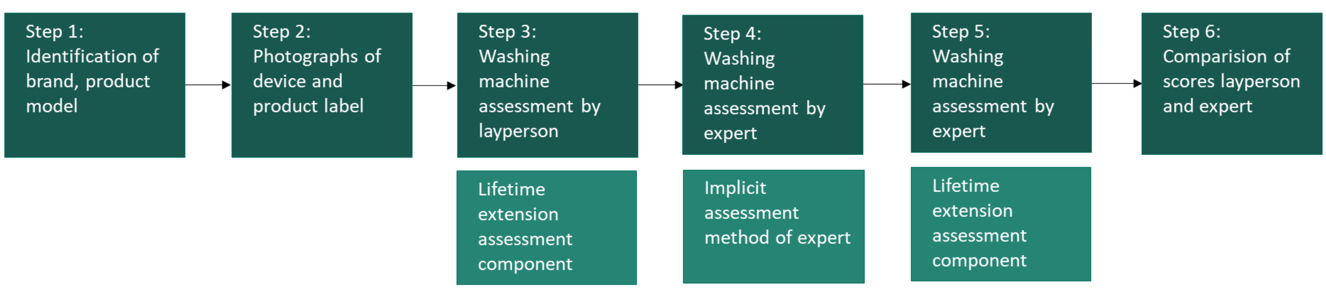


Figure 7-1: Research design validation for lifetime extension assessment component

A separate printed survey form was available for each washing machine. After noting down the brand and product type in research step 1, photos were taken in research step 2 of all sides of the washing machine and the product label. The photos contribute to the careful registration of the washing machine examined. The coded information on the product label provides information about the product type and year of manufacturer (only for the German brands Bosch, Siemens, and AEG). In research step 3, by the application of a printed form, a washing machine was assessed by the layperson. In the assessment procedure, twelve assessment criteria were scored, and the layperson, based on these criteria, gave a final assessment of whether extending the lifetime of a washing machine was viable or not. In this research setting, the researcher performed the role of a layperson. The layperson represents an employee at the collection location who has little or no technical knowledge of washing machines. Usually, based on limited instructions, an employee assesses whether a washing machine is eligible for lifetime extension. These limited instructions are simulated by using the assessment component. In research step 4, an expert at the collection location was asked to assess a collected washing machine for possible lifetime extension using his own implicit assessment method. The expert is a middle-aged man who has been working at the collection site for two years. As a cooperating foreman, the expert is responsible for the return evaluation of collected white goods products and the repair work that is carried out on washing machines. The expert directs a team of younger employees who unload the washing machines from a truck and determine whether they are viable for lifetime extension. During two previous studies at the collection location, the process of return evaluation was mapped out by means of semi-structured interviews and open observations. A structured observation list has been formulated on the basis of these research results which provides an overview of all checks that an expert can carry out at the studied collection location to determine whether it is possible to extend the lifetime of a washing machine. A total of 34 visual and technical checks have been identified. While performing research step 4, the expert was asked to verbally explain which aspects of a washing machine he inspected. Parallel to this process, the researcher noted on the observation form which checks the expert had carried out. Audio recordings were also made of the expert's explanations for all assessed washing machines. Based on the various checks, the expert, at the end of his assessment method, gave a final assessment as to whether lifetime extension was viable or not.

After completing research step 4, the expert was asked in research step 5 to assess the same washing machine using the lifetime extension assessment component. The expert scored 12 assessment criteria and, based on these 12 assessment criteria, gave a final judgment as to whether extending the lifetime was feasible. Finally, in research step 6, the layperson and the expert verbally compared their final assessment with regard to lifetime extension in a quick scan. Before the research procedure started, the researcher explained the expert the research procedure, the assessment criteria, the answer options and the acceptance standards in the DSS. The validation simulated that all assessment criteria were executed in order to get a full picture of the relevance and applicability of all criteria during a washing machine assessment. In practice, for example, non-acceptable bearings would immediately lead to rejection. After completion of the research, the generated research results were manually entered into SPSS and analyzed by the application of descriptive and inferential statistics techniques.

After the 41 washing machines had been assessed, a semi-structured interview took place with the expert. The aim of this interview was to gain insight into the user experiences of the expert's assessment component and decision process.

Based on the quantitative and qualitative research findings a second version of the assessment component was developed.

7.1.2 Design and validation of assessment component prototype version 2

The assessment component was validated at a WEEE management center in the middle of the Netherlands. In line with the policy of Extended Producer Responsibility, the collection agent collects electronics on behalf of manufacturers. Significant volumes of discarded electronic products arrive at a daily basis at the collection location. Washing machines are a small fraction of these E-waste streams. The current focus of collection agents is mainly on material recycling. However, if there are sales markets for reusable appliances and lifetime extension is therefore economically and technically feasible, appliances will be selected for lifetime extension.

The purpose of the validation was the same as that in the validation of the first version of the assessment component, except that the expert's own method was not investigated. The expert involved was part of the development process for the assessment component. Validation of version 1 of the assessment component has shown that it is crucial to enter the assessment components settings providing information about the collection agent in advance. This is relevant because the collection agent does not harvest parts and does not carry out repair activities on washing machines. Therefore, the assessment process route follows a different path compared to the collection agent described in the previous section.

A total of 34 collected washing machines were assessed during the second validation research phase. The collection agents randomly supplied washing machines for validation. The first validation round took place on December 28, 2022. Due to the number of available appliances, twenty-one washing machines were examined with the assessment component. In a second validation round on January 12 2023, which aimed to increase the sample of washing machines under investigation, 13 appliances were assessed at the same location and under the same conditions. **Figure 7-2** outlines the research procedure for the validation of version 2 of the assessment component. The layperson and the expert, on the basis of an available printed survey form, assessed each washing machine in turn. The research procedure mainly corresponded to the validation of the first version.

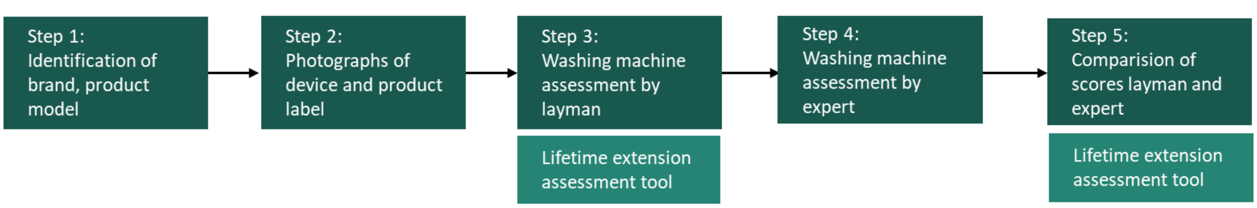


Figure 7-2: Research procedure validation for lifetime extension assessment decision process: version 2

After the brand and product model were registered in steps 1 and 2, the layperson took photos of all sides of the washing machines and the product label. Then, in step 3, the layperson assessed the washing machine based on the assessment component prototype. In step 4, the expert assessed the selected washing machine with the same prototype. In step 5, the layperson and expert verbally compared their final scores for possible lifetime extension. Afterward, a semi-structured interview with the expert took place to be able to evaluate the lifetime extension assessment component prototype. Subsequently, quantitative research results were entered into SPSS and analyzed. For this purpose, descriptive statistics measures and cross tabulation techniques were used. Generated research results were manually entered into SPSS and analyzed by the application of descriptive and inferential statistics techniques.

During the validation of the prototype, the researcher again took the role of a layperson. The head of the technical workshop and repair cafe at a thrift store in the middle of the Netherlands took the role of expert. As a partner of the E-novation Hub, this thrift store takes care of the repair and collection of discarded electronic devices. The expert is a middle-aged man with a technical background and extensive knowledge and experience in the repair of electronic products, including white goods. The expert has been involved in the development of the lifetime extension assessment component at a preliminary phase. As a result, the expert already had extensive prior knowledge of the assessment component. In line with the first validation study, this process simulated that all assessment criteria were assessed in the component, even when the rejection of a specific criterion would normally lead to aborting the procedure. Before the research procedure took place, the researcher explained and instructed the expert on how to perform the lifetime extension assessment procedure. Before the research procedure started, the layperson and assessor jointly assessed a washing machine with the help of the assessment component, whereupon the research procedure began.
After the assessment of 34 washing machines, a semi-structured interview took place with the collection agents' expert to evaluate the lifetime extension assessment.

7.1.3 Design and validation of assessment component prototype version 3

A third version has been developed based on the research findings regarding the previous version 2 of the assessment component. This version was discussed during a working session with the client. Points of attention during this working session concerned the justification of the selected assessment criteria, the order of the assessment criteria, and the definition of acceptance standards. The feedback points from the expert have been incorporated into the final version of the assessment component.

As explained in previous versions, the system development focused mainly on identifying critical assessment factors. The validations clarified the extent to which the layperson and expert gave similar assessments and scores for the collected washing machines and which paradigms affected their scoring. The assessment process was still paper-printed in the first and second versions. Based on the previous validation research results, a digital application of the assessment component has been developed. The digital application aims to demonstrate the low-level functionality of the lifetime extension assessment component. In the application, the assessment process is completed step by step.

The digital assessment component was tested at the WEEE management center, where version 2 of the assessment component had been validated. The layperson, a 27-year-old E-novation Hub employee with a bachelor's degree but no technical knowledge of washing machines, was asked to assess 11 available discarded washing machines. The decision was made to involve a well-educated layperson because the linguistic formulation of the assessment criteria and answer options in the assessment component require average language skills.

The layperson was invited to use the digital application on a smartphone to assess whether the discarded washing machines were eligible for lifetime extension. The researcher explained all the assessment steps beforehand, clarifying each step's relevance and how an answer option should be interpreted. The correct procedure for a bearing test was also practiced pre-assessment. The researcher assessed three washing machines together with the layperson as an exercise. For each washing machine, a stopwatch was used to determine how much time the layperson needed to assess a washing machine with the digital assessment component.

After completing the assessment procedure, the layperson evaluated the usability of the lifetime assessment component prototype. For this purpose, the layperson was presented with eight usability statements, which could be scored on a five-point Likert scale, ranging from "strongly disagree" to "strongly agree."

7.2 Design and validation of assessment component prototype version 1

7.2.1 Identification of assessment criteria

Assessment criteria for the decision-making process for the viability of lifetime extension were inventoried in **Section 6.2**. However, the current restrictions on data availability and accessibility for collection agents, the limited maturity of their digital infrastructure, and the large throughput of discarded washing machines that are predominantly mechanical and, therefore, do not generate data, hinder the process of checking the developed assessment criteria. Interviews with repairers reveal that collection agents often do not have access to software applications which provide access to the data stored in washing machines. These restrictions mean that, in the current circumstances, applicable assessment criteria that can be tested by collection agents must be selected. Despite these limitations, however, derivative assessment criteria have the potential to provide insight into the feasibility of lifetime extension for collected washing machines. During interviews with repairers and participatory observations by the researchers in technical workshops where washing machines are repaired, it became clear which alternative derived assessment criteria could be as included in the lifetime extension decision process. Another consideration is that the client indicated that a basic decision-making process should involve assessable criteria. **Table 7-1** presents a possible overview of these derived assessment criteria and explains the relationship with the assessment criteria in **Table 6.2**. The table also presents how the information can be obtained.

Assessment criteria	Corresponding assessment crtiteria in table 6.2	Explanation	Information source
1. Washing machine type	Physical product properties	Front loaders are the most common washing machines on the Dutch market and have a higher level of repairability	Visual inspection
2. Brand	Product quality	Compared with other washing machines, the product quality of German brands on average is higher Product quality relates to attainable lifetime of a washing machine	Product label Frontside washing machines
	Repairability	Compared with other washing machines, the level of repairability of German brands on average is higher	
	Energy and water efficiency	Compared with other washing machines, the product quality of German brands on average is higher	
	Market demand	In general, second-hand white goods sellers and thrift stores indicate a solid market demand for appropriate German washing machines. Differentiation of market demand for individual washing machines has no added value	
3. Initial catalogue price	Product quality	Product quality relates to attainable lifetime of a washing machine	E-commerce retailers' pricing websites.
4. Year of construction	Residual lifetime	Based on average lifetimes of washing machines, their expected residual lifetime can be calculated	Product label
5. Energy efficiency	Environmental performance	Energy consumption affects the ecological impact of a washing machine	Energy label
6. Water efficiency	Environmental performance	Water consumption affects the ecological impact of a washing machine	Energy label
7. Quality of bearings	Failure diagnostics	A bearings test is critical because of limits to the economic and technical feasibility of possible repair	Bearing test
8. Functioning of washing machine	Product status	The functioning of the washing machine indicates whether the device is viable	Plug test
9. Washing machine completeness	Completeness of washing machine	The completeness of a washing machine affects the extent to which spare parts are required to repair the product, if necessary, e.g., soap dish, control panel, door, door hanging, and housing	Visual inspection
10. Dents	Physical condition of device	Dents reveal the physical condition of washing machines and indicate the usage intensity and treatment behaviors	Visual inspection
11. Rust damage	Physical condition of device	Rust traces reveal the physical condition of washing machines and indicate the usage intensity and treatment behaviors	Visual inspection
12. Safe power cable and plug	Treatment behaviors Completeness of washing machine	The quality of the power cord and plug might cause adverse safety risks. The lack of a power cable and plug hampers repair	Visual inspection

Table 7-1: Elaboration of possible derived assessment criteria

The assessment criteria were presented to a repairer of a thrift store for critical review during a work session. The repairer was selected because of his extensive experience collecting, diagnosing and repairing washing machines. Their most important feedback was that the initial list price of a washing machine, especially if it is more than ten years old, could not, in many cases, be traced. The repairer also indicated that, although information about energy and water efficiency performance can be found in printed or digital product manuals, this information is not immediately available at a collection agent's location in the current situation. Owing to this obstacle, it was decided not to include the initial catalog price and energy and water efficiency assessment criteria in the decision-making process.

Based on the selected assessment criteria (numbers 1, 2, 4, 7, 8, 9, 10, 11, and 12), a first version of the decision process was developed during a working session with the thrift store repairman. For ease of the assessment component's usability, it was decided to split the completeness category of the washing machines into specific washing machine parts, such as the door, door suspension, control panel, and soap dish. In the decision-making process, the assessment criteria are tested sequentially. Working together with the repairman, the assessment criteria were ranked in order of priority. Generic assessment criteria such as front loader, functioning, brand, and age were prioritized over the bearing test and visual checks.

The assessment criteria correspond to working session response categories. Two possible response categories can be scored for the generic factors washing machine type, functioning, brand, year of construction, and bearing test. Three answers are possible for the other assessment criteria in the decision-making process. The middle answer category offers the possibility of product recovery. In consultation with the repairman, standards were developed for each assessment criterion that supports a collection agent assessor in coming to a decision on possible lifetime extension of a washing machine, for example, whether the brand, the bearing test results, and the completeness of a washing machine are acceptable. The average lifetime of a washing machine is twelve years (Prakash et al., 2020; Tecchio et al., 2019). The standard for acceptance was set at 10 years because this offers the possibility of an acceptable residual life of 2 years.

7.2.2 Validation results assessment component

This section explains the results of the validating study. 78% of the investigated washing machines assessed were from a German brand. 22% of the washing machines examined were not German.
If possible, and based on the information on the product labels, the year of construction of the washing machines was determined. For 16 of the 41 washing machines, it was not possible to determine the year of construction via the product label. 44% of the investigated washing machines were less than 10 years old; the remaining 56% of the devices was are older than 10 years.

Figure 7-3 reveals that the layperson and the expert have different perceptions of the possible lifetime extension of the investigated washing machines when using the assessment component. After the assessment, the layperson selected three washing machines for lifetime extension. Based on the assessment criteria and standards, the layperson selected and rejected 3 and 38 washing machines respectively for lifetime extension. The expert selected 21 washing machines for lifetime extension and rejected 20 devices.

Overall possibility of lifetime extension / expert

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	21	51,2	51,2	51,2
	No	20	48,8	48,8	100,0
	Total	41	100,0	100,0	

Overall possibility of lifetime extension / layman

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	3	7,3	7,3	7,3
	No	38	92,7	92,7	100,0
	Total	41	100,0	100,0	

Figure 7-3: Selected and rejected washing machines according to layperson and expert

The Cohen's kappa measure was applied to check the quantitative measure of inter-rater reliability. The measure corrects how often the raters may agree by chance. **Figure 7-4** shows that the Cohen's kappa rate not significant agreement between the rates merely as a result of random choice. The difference between the layperson's and expert's assessment scores is explainable because the layperson strictly adhered to the set standards while performing an assessment. For example, a washing machine that was older than ten years, had a missing power cable, or was missing a housing part led to the rejection of the washing machine according to the initial design of the assessment component. On the other hand, the expert applied the acceptance standards more flexibly despite the researchers' instructions. In many cases, the expert saw opportunities for extending the lifetime of a washing machine. The experts' positive attitude towards lifetime extension can be explained by the fact that the selected washing machines were to be repaired at the collection agents' location and harvested parts from the collected washing machines were to be reused in the repair process.

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	,044	,079	,556	,578
N of Valid Cases		41			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Figure 7-4: Inter-rater reliability of layperson and expert according to Cohen's kappa

In addition to the assessment component, the expert applied his tacit assessment method to check whether lifetime extension of washing machines was possible. **Table 7-2** provides insight into the checks the expert carried out most frequently. The expert verbally mentioned these checks explicitly during the assessment of the washing machines.

Table 7-2 reveals that the expert assesses a collected washing machine mainly on brand, the visual condition of a washing machine, any missing parts, the functioning of the bearings, and an estimation of the washing machine's age; these checks match the assessment criteria in the lifetime extension assessment component. In their assessment, the expert attaches significant importance to the visual condition of the washing machine, while the actual age of the washing machines is less relevant to him.

The extent to which the expert's assessments, based on his method and the lifetime extension assessment component, corresponded was statistically examined. **Figure 7-5** shows that the expert's assessments based on his tacit method and the developed assessment component almost perfectly agree. However, this close coincidence between the two assessments should be considered critically. When performing the assessment component criteria, the expert tended to interpret the acceptance standards loosely. During validation, the expert stated that the collection agent was inclined to select German washing machine brands for lifetime extension if the physical condition of an appliance allowed it. Regular large volumes of incoming high-quality German washing machines make it attractive for the collection agent to harvest and reuse their parts. Consequently, the expert, in contrast to the layperson, selected German washing machines for lifetime extension more readily.

Checks expert	Number of applied checks (n=41)	%
Brand	41	100
Visual condition of washing machine	36	88
Missing parts	36	88
Bearing test results	36	88
Age based on visual impression	14	34
Product type	12	29
Power reception	5	12
Age of washing machine	4	10
Expected market demand	3	7
Possibility of harvesting spare parts	3	7

Table 7-2: Expert's lifetime extension checks

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	,902	,067	5,778	<,001
N of Valid Cases		41			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Figure 7-5: Inter-rater reliability: Cohen's kappa results for expert's method and lifetime extension assessment component

Another crucial point is that during the validating research, the expert first applied his own methodology and then applied the developed assessment component. A possible experts' confirmation bias might, therefore, have affected his assessment scores. The researcher observed that the expert tended to apply his own method to the scores of the various assessment criteria. Despite the researcher's instructions, the rigid acceptance standards in the decision process were in some cases broadly interpreted by the expert. These observations explain the high Cohen's kappa between the two assessment methods used by the expert. In contrast, the layperson applied the acceptance standards rigidly and consequently selected significantly fewer washing machines for lifetime extension.

After the 41 washing machines were assessed, a semi-structured interview took place with the collection agents' expert to evaluate the lifetime extension assessment component (see **Appendix H**). Relevant feedback points from the expert were:

- The current tacit assessment method used by the collection agent requires background knowledge of washing machines and specific brands. It takes a layperson time to acquire this knowledge. The assessment component is therefore helpful for a layperson with limited background in the lifetime extension assessment of washing machines.
- The expert stated that the assessment process should be aborted immediately if an assessment criterion has not been met.
- According to the expert, the selected assessment criteria and response categories which make up the assessment component, could differ per collection agent. For example, if a collection agent only selects German washing machine brands, harvests their parts, and conducts repair activities, then the selection of the assessment criteria will be different from that of another collection agent who does not repair washing machines.
- The expert stated that the assessment criterion to ask a discarder to assess whether a washing machine is functioning or to perform a power test is irrelevant since most of the washing machines are delivered anonymously. Many washing machines lack a power cable and plug, thus hampering a power test.
- There is no market demand for a washing machine with a loading weight limited to less than 7 kilograms.
- The number of photos taken of a washing machine can be reduced to save assessment time.
- The expert stated that the limited number of response categories is acceptable.
- The expert emphasized that lifetime extension of washing machines is only economically viable if parts are harvested, and if employee wage costs are low by cooperating with rehabilitation institutions.

Based on the researchers' unstructured observations during the validation research (see **Appendix I**), it has become essential to determine which lifetime extension strategies collection agents regularly apply (such as overhaul, repair, and the harvesting of parts). During the validation research, it became clear that this strongly influences the assessment scores of the expert. Namely, a collection location that harvests parts creates favorable conditions for overhauling or repairing washing machines. It also became apparent when scoring assessment criteria that answer categories can be interpreted in multiple ways due to their subjective character. Another consideration is that a washing machine's year of construction cannot be determined for all washing machine brands. The expert clarified that an inspection of the visual condition of a German washing machine brand, in combination with the availability of harvested parts, is essential. Extending the lifetime of washing machines equipped with digital technologies is also, in many cases, not feasible because the collection agents do not have access to software that provides access to the devices. This poses a significant threat to collection agents given that the number of digital washing machines will increase in the coming years.

7.3 Validation of assessment component: version 2

7.3.1 Modification of assessment component

The assessment component was modified based on the validation results for the first version. The assessment component cannot perform the check whether a washing machine is functioning because many power cables have become detached from their respective machines. Moreover, the assessment time at a collection location is too limited to carry out a technical test on whether a power cable actually provides power to an appliance if it is present. The year of construction of a washing machine can be indicated by the product label or estimated based on the vertical or horizontal notches on the left- and right-hand side of the machine. The visual checks have, however, remained virtually identical. Due to the complexity of establishing the existence and proper functioning of the door hanging, a separate assessment criterion has been defined for the door suspension. Based on the feedback from the expert, the order of the assessment criteria in the component has been adjusted on several points. For example, lifetime extension possibilities are affected more by passing the bearing test than by the construction year of a washing machine. As a result, the answer categories have been reduced to 2 options. In addition to providing simplicity, this challenges an assessor to think critically about the acceptance standards when scoring each assessment criterion. The acceptance standards for each assessment criterion are detailed. Another modification is that the age standard has been raised from 10 years to 13 years for German brands. Namely, the validation research of the assessment component version 1 revealed that the expert did not reject a washing machine because of its age of 10 years. According to the expert, a washing machine aged between 10 and 15 years is still acceptable if the device's physical condition is appropriate.

7.3.2 Validation results

During the second validation research procedure, 70.6% of the assessed washing machines were German brands. The average age of the assessed washing machines was 12 years. This average age corresponds to the established average age of a washing machine (Prakash et al., 2020; Tecchio et al., 2019). 73.7% of the rated washing machines were 12 years old or newer.

Figure 7-6 shows that the layperson approved 15 washing machines for lifetime extension based on the assessment component. The expert, on the other hand, approved 21 washing machines. Unlike the layperson, who carefully adhered to the defined acceptance norms, the expert again qualified substantially more washing machines for lifetime extension.

Overall possibility of lifetime extension / layman

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	15	44,1	44,1	44,1
	No	19	55,9	55,9	100,0
	Total	34	100,0	100,0	

Overall possibility of lifetime extension / expert

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	21	61,8	61,8	61,8
	No	13	38,2	38,2	100,0
	Total	34	100,0	100,0	

Figure 7-6: Selected and rejected washing machines according to layperson and expert

Cohen's kappa value of 0.657 in **Figure 7-7** shows that the raters largely agreed on whether a washing machine was eligible for lifetime extension or not. The differences between the two final assessments can be explained by the fact that the expert tends to repair washing machines until they are once more functional. Such a maximization approach is at odds with the optimization approach that underpins the lifetime extension assessment component. In line with the Pareto principle, common defects that can easily be fixed are repaired, with no time being spent on lengthy, inefficient repairs. This principle contributes favorably to the economic feasibility of repair activities on washing machines. However, the expert's positive attitude towards product recovery might bias the lifetime extension assessment to some extent.

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	,657	,119	4,076	<,001
N of Valid Cases		34			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Figure 7-7: Inter-rater reliability Cohen's kappa

Relevant evaluation points according to the expert are (in random order) (see **Appendix J** for more details):

- The simplicity, ease, and speed of the assessment component appealed to the expert. The limited number of assessment criteria and response categories matched the characteristics of employees at collection locations.
- The expert indicated that the final assessment of the lifetime extension assessment component corresponded with his assessment.
- A limitation of the assessment component was that it did not test for disproportionately high energy consumption, caused by missing data and energy labels. At the same time, as a rule of thumb, it can be assumed that the energy and water consumption levels of German washing machines are acceptable.
- According to the expert, the essence of the assessment component was that the assessment of lifetime extension involves visual testing for the physical condition of the washing machine, the completeness of the device, and the condition of the bearings.
- The expert stated that the age check is not feasible because details of the manufacturing year are often unavailable for many washing machine brands. During the washing machine assessment phase, the expert failed to estimate the age of washing machines based on their appearance. Therefore, the question regarding estimating the age of the washing machine would seem to be unfeasible in practice. Such an estimate requires profound product knowledge on the part of the employee, which they often do not possess. Employees with limited knowledge and technical background should, nonetheless be able to assess collected washing machines.

- The lack of information and data on product and usage information and the unknown reasons why a discarder delivers a washing machine at a collection point limited objective decision-making.
- According to the expert, the dichotomous response categories for each assessment criterion should be maintained. In the event of an assessor hesitating in their decision as to whether lifetime extension is feasible or not, a professional repairer should then check the washing machine.

7.4 Validation of lifetime extension assessment component version 3

7.4.1 Description of assessment process

The final version 3 of the assessment component and corresponding assessment process was developed based on the previous validation research results. The structure of the corresponding assessment process is detailed in **Figure 7-8**. In the first phase of the assessment process, an assessor enters the settings of the component. The settings depend on the existence of repair facilities and the harvesting of washing machine parts are discriminating factors. Based on these discriminating factors, two process routes have been distinguished in the assessment component. The assessment criteria in both decision process routes are the same, but the number of possible response categories differ per assessment criterion. For the second process route, the middle answer category allows product recovery that might contribute to the lifetime extension of a washing machine.

The second phase of the assessment process consists of taking a photograph of the front side of the washing machine and its product label. These photos contribute to the inventory and transparency of all washing machines that arrive at a collection agent. The photos might also be used in future to digitally assess the physical condition of a collected washing machine.

The third phase of the assessment process relates to the assessment of generic assessment criteria, while in the fourth phase basic visual checks are performed. For phases 3 and 4, all acceptance standards must be met in order for the washing machine to be eligible for lifetime extension. If an assessment criterion has not been met, the assessment process stops immediately. Although without the scope of this study, parts or materials can be harvested from rejected washing machines, if possible.

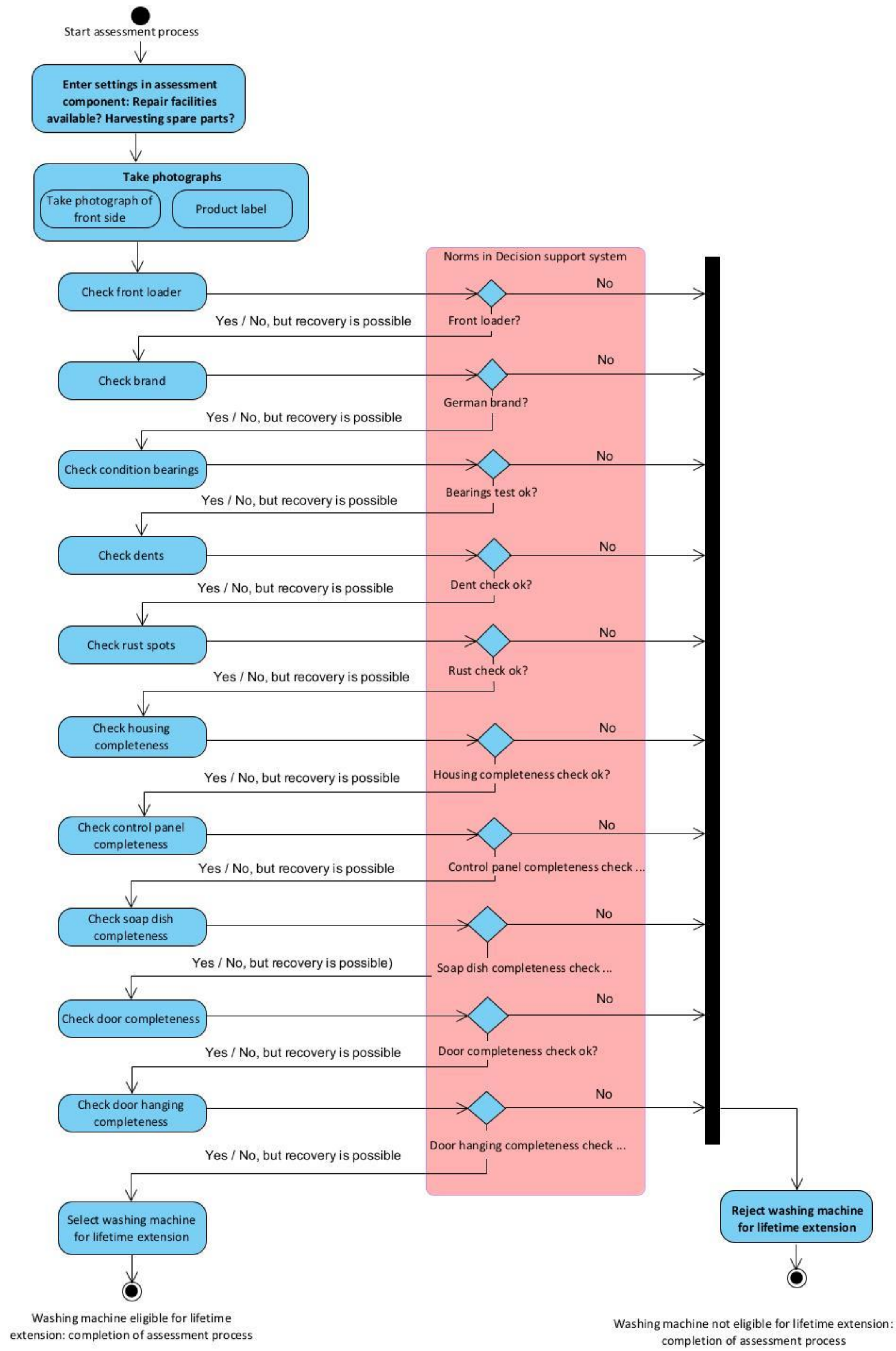


Figure 7-8: Decision process for lifetime extension assessment component (version 3)

7.4.2 Design of digital assessment component

In consultation with the client, the employment of a software application was decided upon that is easy to use, easily adaptable, and represents the intended functionalities of the assessment component prototype in the least complex way possible. The simple and statistical nature of the validated prototype offers opportunities to apply survey application tools, such as Google Forms, Microsoft Forms, and Qualtrics. Such tools offer the possibility to develop and distribute a survey form efficiently. These survey applications also have a camera function that allows photos of a washing machine and the product label to be taken. Furthermore, the generated data are automatically stored in a database. In the end, the Qualtrics web-based survey software application was selected. Qualtrics allows for the assessment component to be customized and supports complex survey configurations, such as “if…. then” conditions. Qualtrics enables data collection at multiple locations and on a large scale. The data are automatically collected in a database. Qualtrics also provides descriptive statistics capabilities. Exported results enable the application of interpretive explanatory statistics applications, such as SPSS.

The Qualtrics application is structured according to the process activities in **Figure 7-8**. As mentioned above, the harvesting of parts and repairing washing machines at the collection facility is a discriminating factor. In the first phase of the application, therefore, the assessor is questioned as to whether repair activities and parts harvesting are performed in the initial phase of the process. Then the assessor is asked to take a picture of the washing machine’s front side and product label. The photo of the product label contributes to product identification. The photo of the front of the washing machine gives an impression of the condition of the washing machine and supports product identification. After taking the photographs, the assessor is requested to check generic assessment criteria: type of washing machine, brand, and the condition of the bearings. The next group of assessment criteria relates to the visual inspection of dents, rust and the completeness of the housing, control panel, soap dish loader, door, and door hanging.

Acceptance standards are attached to each assessment criterion. The Qualtrics application automatically proceeds to the next assessment criterion if an acceptance standard has been satisfied. If an assessment criterion has not been met, the assessment of the washing machine stops, and the assessor receives a visual message that the machine is not eligible for lifetime extension. If all assessment criteria are met, the assessor receives a visual message that the washing machine is eligible for lifetime extension.

Figure 7-9 shows screenshots of the assessment component prototype on a smartphone.

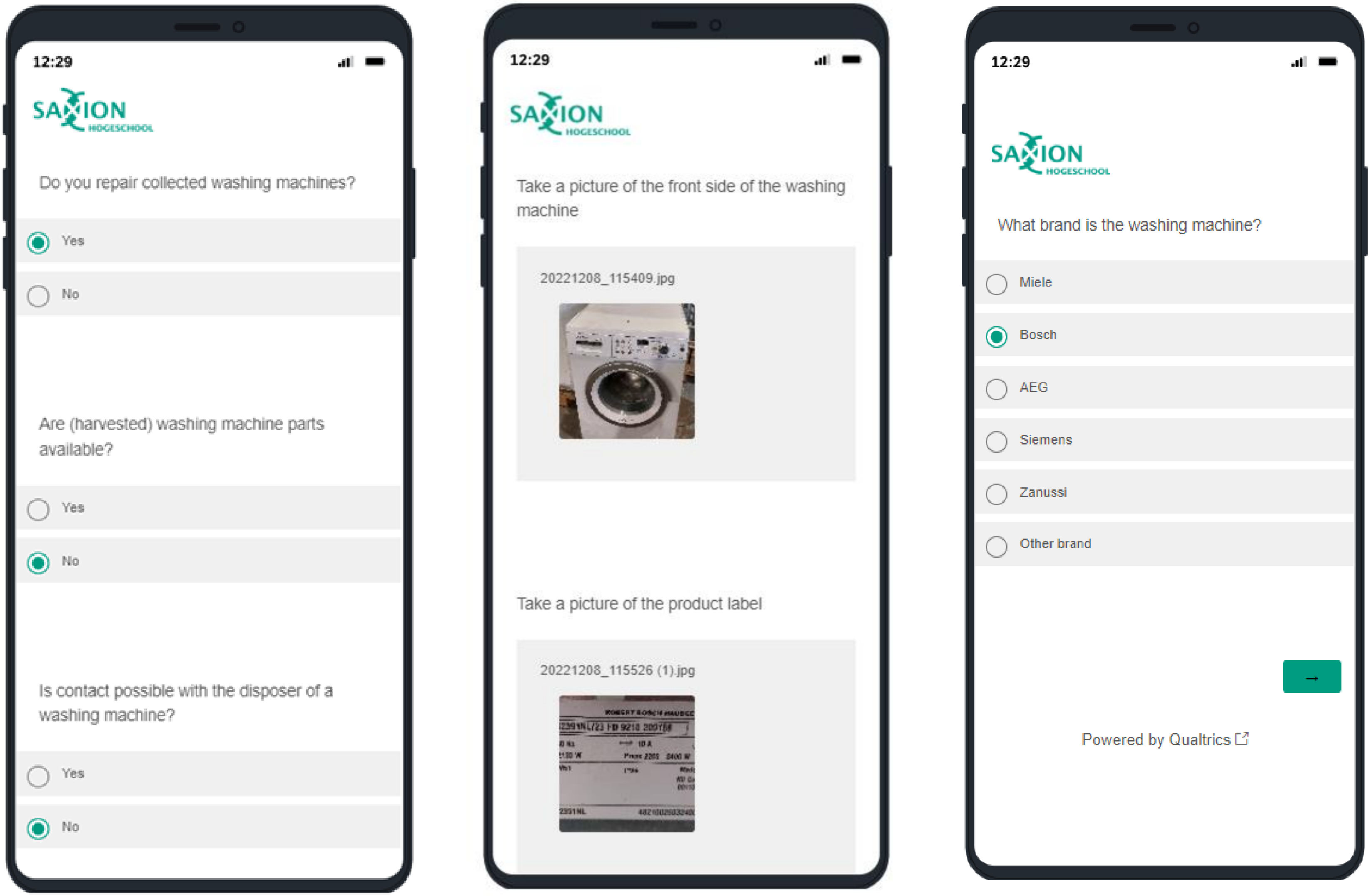


Figure 7.9: Screenshots of lifetime extension assessment component prototype (continued on next page)

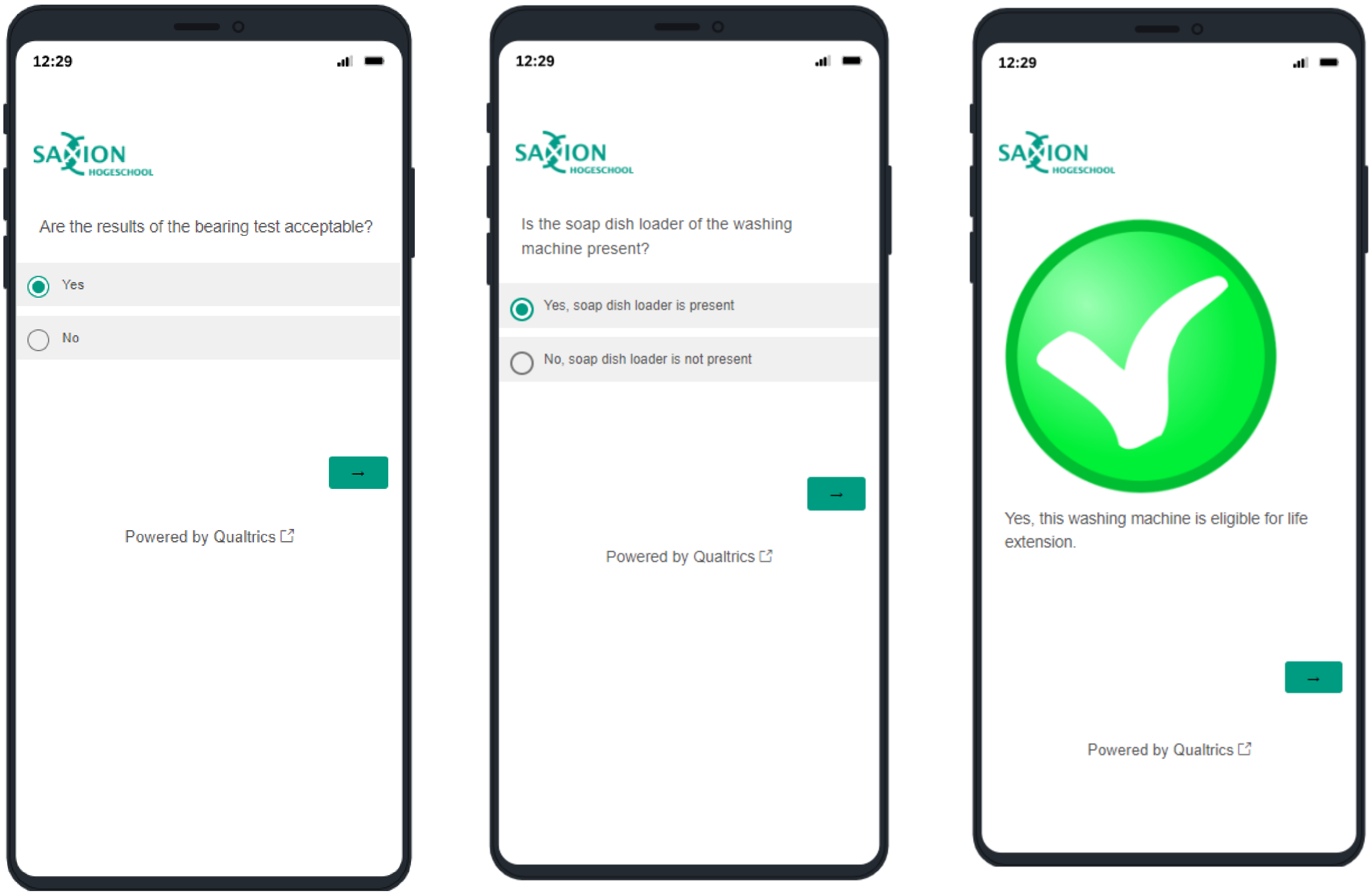


Figure 7-9: Screenshots of lifetime extension assessment component prototype (continued from previous page)

7.4.3 Validation of digital assessment component

This section explains the validation results of the digital application of the assessment component. The average assessment time the layperson to assess a washing machine was 106 seconds, With a minimum assessment time of 46 seconds and a maximum assessment time of 216 seconds. **Table 7-3** demonstrates that for device numbers 2 and 3 the assessment procedure takes less time if the acceptance standards of the bearing test have not been met. It took the layperson between 148 and 190 seconds to assess the washing machines deemed suitable for lifetime extension. Logically, the assessment time is short if a washing machine is rejected early in the assessment process (for example, washing machines 2, 3, 7, 8, and 10).

Id number device	Brand	Required assessment time (seconds)	Assessment result
1	Bosch	138	Assessment terminated after rejection of incomplete door hanging
2	Samsung	57	Assessment terminated after rejection on brand.
3	Samsung	46	Assessment terminated after rejection on brand.
4	Miele	190	Assessment was successful; lifetime extension is possible.
5	AEG	216	Assessment was successful; lifetime extension is possible.
6	Miele	148	Assessment was successful; lifetime extension is possible.
7	Bosch	55	Assessment aborted after rejection on bearing test.
8	Siemens	68	Assessment aborted after rejection on bearing test.
9	Miele	78	Assessment aborted because the door could not be opened
10	Bosch	61	Assessment aborted after rejection on bearing test.
11	Bosch	115	Assessment aborted because of missing housing.

Table 7-3: Lifetime extension assessment results

After the assessments of the available washing machines were completed, the layperson was invited to evaluate the usability of the lifetime assessment component prototype. For this, the layperson was presented with eight usability statements. which could be scored on a five-point Likert scale, ranging from strongly disagree to strongly agree (see **Table 7-4**).

Table 7-4 explains that the layperson perceived the assessment component to be helpful, due to the comprehensibility of the assessment criteria and the simplicity of the answer options. However, the table also shows that the layperson came across some difficulties. According to the layperson, measurable acceptance standards for the assessment criteria when scoring are missing: the bearing test results led to doubt about the correct answer category, and the layperson had the impression that she needed more experiential knowledge to enable a quick assessment. During an additional open evaluative interview with the layperson, she indicated that after several assessments, she noticed that her assessment skills improved due to the repetitive nature of the assessment component. The layperson estimated that a considerable reduction of the assessment time should be possible after a day of working with the assessment component. During the assessment, the layperson noticed that several assessment criteria could potentially be combined during the visual inspection. Moreover, the layperson approved of the binary nature of the answer options; it forced her in a positive way to make a clear choice. The layperson also indicated that supporting images would help to make the acceptance standards explicit in a subsequent version, e.g., what is an acceptable or unacceptable rust spot? She believes this is relevant because she tended to rely on her subjective judgment when scoring some assessment criteria.

Furthermore, the layperson revealed that she values the layout of the assessment component. As a suggestion, she mentioned that several assessment questions could be presented on one screen. A critical side note arises from the layperson having pressed the wrong answer option during an assessment, leading to her then failing to answer the question again. The assessment component should allow for correction of recorded answers. Another critical remark provided by the layperson was that the linguistic answer options caused confusion because they were not unequivocally positive or negatively oriented.

Please score the following statements:	Strongly disagree	Disagree	Neither disagree or agree	Agree	Strongly agree	Layperson's explanation
1. The criteria in the assessment component are understandable to me.					X	"The criteria were easy to understand. The text was sufficiently understandable. I didn't need any additional explanation. The closed questions were clear to me and unambiguous."
2. The assessment criteria are easy to score.		X				"The assessment criteria were difficult to score. Acceptance percentages would be helpful to me. E.g., "10% rust on the entire unit is acceptable". Provide a clear framework of what is and what is not acceptable. For example, clarify what an acceptable dent is. Such an approach prevents a subjective score. It is better to have fixed answer options. Thus, when scoring, ensure objective, unambiguous choices, and acceptance standards."
3. The answer options in the assessment component are difficult to understand.	X					"The answer options are all clear to me. The answer options fit well with the question. It is nice to have 'yes' and 'no' answers because it pushes me to make a decision, for instance, during the bearing test. Otherwise, I often would have chosen a medium answering scoring category."
4. Selecting the right answer option when scoring several assessment criteria was difficult.			X			"Choosing the right option for the bearings test and the rust criteria was difficult for me. While performing the bearing test, I could not see clearly deep inside the washing machine. Because of that, it was hard to determine whether my answer was correct. On the other hand, soap dish and door assessments were easy to perform."
5. I needed minimal time to score the several assessment criteria.				X		"Less time was required to score each question in the assessment component. The more washing machines I assessed, the easier it got for me."
6. The assessment component requires background knowledge about washing machines.					X	"The assessment component required a lot of experiential knowledge. For example, how to open a washing machine door, where to find the product label, and how to perform a bearing test properly. After a day of assessing washing machines, I would understand the ins and outs of the assessment. Consequently, I would perform the assessment better and faster than today. In addition to this experiential knowledge, little specific technical knowledge is required."
7. Performing the bearing test was difficult for me.					X	"Performing the bearing test was difficult for me. A visual image of the inside of a washing machine would help me determine where the bearings in the washing machine are located. That could help me a lot in judging the quality of the bearings. I actually need a mini training session to understand how a washing machine's bearings function and what happens when the bearings are broken."
8. Summarized, the lifetime assessment component was helpful for me when assessing washing machines for possible lifetime extension.					X	"It is 100% a usable component. The questionnaire achieves its goal."

Table 7-4: Evaluation of application of assessment component by layperson

7.5 Migration plan assessment component

A migration plan for CirkelWaarde has been developed to support the implementation of the lifetime extension assessment component. The migration plan includes various work packages and deliverables supporting the assessment component's current implementation at collection agents (see **Figure 7-10**).

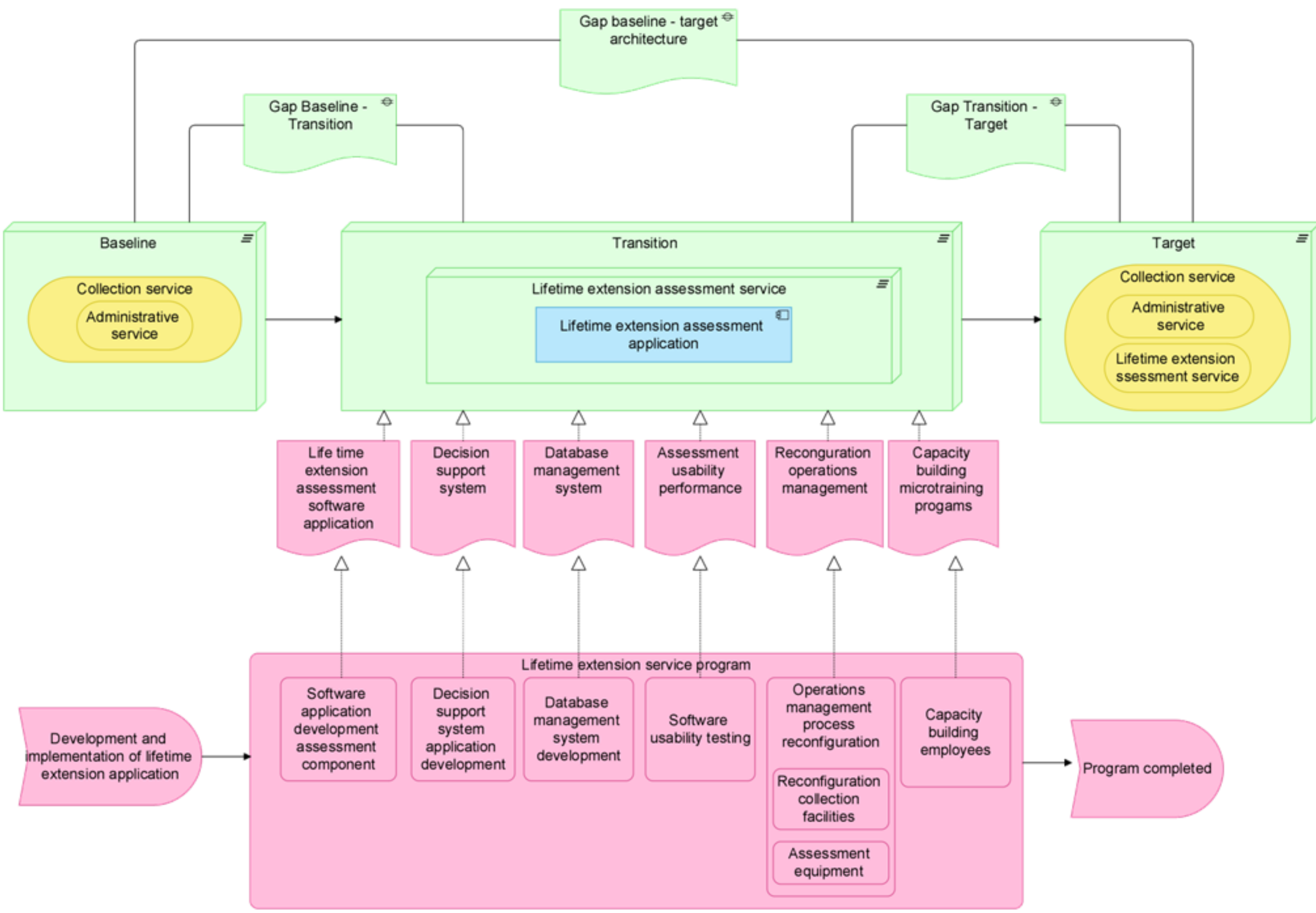


Figure 7-10: Migration plan implementation of lifetime extension assessment component 2024

Central to the migration is the software application development of the assessment component. As mentioned, in the study the operation of the assessment component was demonstrated in a online survey software application. Implementation of the assessment component on a large scale and the future link with DPPs requires early anticipation of these developments in the software engineering process. This requires thoughtful choices in the technical architecture design, the application architecture, the system interface design, and the database design. As part of the software application, the DSS must be digitized. Despite the static character of the DSS in the current situation, digital technologies in washing machines and DPPs will eventually require a DSS that has a dynamic character. In line with this, a unique assessment process route can be defined for each collected washing machine.

Future system dynamics should be considered early in DPP and DSS application development. DBMS development is required to allow users to create, read, update, and delete data in a database. The detailed DPP requires a validated data model to structure the data in the database and ensure thoughtful relations among the data objects. During DBMS development, various issues must be addressed, such as the data model type, data consistency, data quality standards, data formats, data security, data access, and data protection. An important DBMS consideration is in which environment the DBMS is housed, e.g., in a cloud or blockchain environment.

Another work package relates to the usability testing of software applications. The validated assessment tool uses linguistic formulations that are difficult for collection agents' employees to understand. The development of standardized and visual response categories for each assessment criterion should make the application accessible to employees who do not speak the Dutch language and who match their cognitive capabilities. For employees, the standardized and visual software elements must be methodically tested on a broad spectrum of usability aspects. The insights this provides can be included in developing the software application. Business-IT alignment is crucial during implementation. The current operations at collections agents must be aligned with the systematized method of assessment of washing machines. This requires changes in the current processes and procedures, reconfiguration of the collection facilities, and IT and physical equipment to carry out the assessments. In addition, it is essential to support collection agents' employees in collecting, handling, and assessing discarded washing machines. Such a value-driven approach requires capacity-building initiatives, such as micro training, workshops, and mentoring that teach employees how to use the assessment tool and recognize the residual value of washing machines.

7.6 Summary and conclusion

The current assessment of the lifetime extension of collected washing machines is often based on implicit, subjective considerations. This chapter has explained 'the lifetime extension assessment component in the current circumstances and the related decision process for collection agents. Specification of the decision process was conditional to the development of a digital assessment component application that supports collection agent assessors during the assessment of collected washing machines. One problem encountered during the system development process was that most of the identified assessment criteria and their related indicators (see **Section 6.2**) could not be tested due to the current asymmetry of information in the collection agents' washing machine ecosystem. Because of this restriction, alternative assessment criteria with optimal, predictable values for the lifetime extension of collected washing machines were identified. Many of these assessment criteria were identified during participatory observations in technical workshops where washing machines are repaired and during interviews with professional repairers. The assessment criteria are selected, ordered and prioritized in a decision-making process. The existence, or not, of repair facilities and the harvesting of parts determines the decision process and the number of response categories. During the validation studies, it became clear that collection agents who repair are inclined to repair collected washing machines as much as possible, even if this takes extended periods of time. The developed assessment component therefore challenges them to focus exclusively on repairable common failure modes. During the validation studies, it took the experts some effort to relinquish their tacit working method. Research carried out with a layperson clarified that the digital assessment component's basic design helps determine whether lifetime extension is possible based on the application of reason. The mobile application requires technical knowledge of washing machines and practical experience to score the assessment criteria confidently. According to the layperson, in a future design of the lifetime extension assessment component, visualization, and micro-training sessions could help collection agent employees who have limited technical competencies operate the application.

In a migration plan, defined activities guide collection agents in implementing the assessment component in the current situation. The development and realization of a DBMS, the software development of the assessment component application, and the adjustment of the current operational management processes are essential measures.

8 Conclusion and future work

This chapter presents the main findings, contributions, limitations and future research outlook for the current EngD study. **Section 8.1** discusses the main design and research findings. **Section 8.2** explains the contributions of this design research study to the scientific literature, governmental institutions, and collection agents. **Section 8.3** presents the limitations of the conducted design research. **Section 8.4** elaborates on practical recommendations for the CirkelWaarde client and recommendations for future research.

8.1 Main findings

As stated in the introduction to this EngD study, the lifetime extension of discarded washing machines potentially offers significant business opportunities. Product lifetime extension business models aim to create value for customers in second-hand markets by applying circular strategies such as Reuse, Repair, or Refurbishment. The value creation process in the reverse logistics supply chain determines the utilization of the residual technical and economic value of collected washing machines. Collection agents play a critical role in the transition to a circular economy by properly collecting discarded washing machines and objectively assessing their residual value.

Analyses revealed that the envisioned circular role of collection agents depends on multiple factors, such as product and usage data availability, the lack of practical lifetime extension assessment instruments, and the features of the current and projected future washing machine ecosystem in which forward and reverse supply chain stakeholders act. Thus, during the system development process, it became clear that lifetime extension should be approached from multiple perspectives. The system artifacts defined reflect the multiple perspectives of this design science study. The detailed system artifacts in this EngD study are interrelated and built upon each other in a sequential development process.

The complexity of the client's lifetime extension assessment problem and the required multiple perspective approach fit well with the three-cycle view of design science research and the EngD program Business & IT. Scientific literature and domain expertise on WEEE management and product lifetime extension guided the design research of the system artifacts. Positioning the system artifacts in their contextual environment during the system development process helped to understand and evaluate their effectiveness. The EngD study has resulted in a pragmatic lifetime extension assessment component. On a theoretical level, the study has contributed to developing knowledge of decision support for the product lifetime extension of collected washing machines (see **Section 8.2.1**).

Below, the EngD study's design and research findings are structured based on the research questions outlined in **Section 1.3**.

1. What are the properties of the current and future washing machine ecosystem in which collection agents of discarded washing machines operate?
The model-based analyses performed in this EngD study revealed that the current washing machine ecosystem mainly focuses on materials recycling. Stakeholders in the forward supply chain (manufacturers, importers, wholesalers, and retailers) greatly affect the possible lifetime extension of discarded washing machines (see **Sections 2.2 and 2.3**). Product design strategies based on linear economy principles, poor product repairability, transaction-based business models, and limited information sharing hamper lifetime extension of appliances on a large scale. Information sharing across washing machine ecosystem stakeholders mainly occurs in the forward EEE supply chain but is limited in the reverse supply chain. Consequently, collection agents are confronted with limited availability and accessibility of data, which hinders objective assessment of collected washing machines.

The research results showed that, in line with the principle of a linear economy, forward supply chain actors are mainly driven by product innovation, operational excellence, and profit (see **Section 2.1.3**). Multiple observations and interviews with washing machine ecosystem stakeholders confirmed that using the residual value of a collected washing machine is not an integral part of the business models of forward supply chain actors. Affected by the producers' extended responsibility, washing machine collection agents often opt for low-value circular strategies, such as materials recycling. The high costs of product repair, caused by high spare part and labor costs, discourage collection agents and repair facilities from extending the lifetime of washing machines on a large scale. Hence, their collection services focus solely on distributing, sorting, and E-waste administration of collected consumer electronics.

a. **Which technical, technological, and environmental factors affect lifetime extension of collected washing machines?**

The literature review revealed that the technical feasibility of lifetime extension of collected washing machines is influenced by the design principles underlying a washing machine product. The design strategies used by washing machine manufacturers largely determine the durability and repairability of a washing machine. The product and usage data in the future DPPs can contribute to objectifying the lifetime extension assessment. Washing machines equipped with digital technologies, such as Internet-of-Things applications, generate valuable usage data. The literature review revealed that life cycle analyses can provide insight into the ecological impact of extending the lifetime of washing machines. In addition to these factors, the expected market demand for a particular brand and product type of washing machine determines the feasibility of lifetime extension.

b. **How can socio-technical developments in the washing machine ecosystem enhance a circular assessment of discarded washing machines?**

The EngD study clarified that extending the lifetime of washing machines is an issue for a circular ecosystem and cannot be delegated exclusively to collection agents. A systemic, holistic, and product lifecycle approach, whereby collection agents are an integral part of a washing machine’s ecosystem, is required to significantly assess and utilize the residual value in discarded washing machines. For this purpose, two elaborate socio-technical scenarios in **Section 3.1** position the assessment of washing machines for lifetime extension from a systemic perspective. These scenarios were developed around macro developments, expected changing socio-technical regimes, and niche technological innovations. The transition from a linear to a circular washing machine ecosystem, digital technologies in washing machines, data sharing across the ecosystem, and the facilitating role of DPPs are critical system innovation levers that support the data-driven assessment of collected washing machines.

c. How can the value exchanges between collection agent stakeholders in a future value network contribute to the lifetime extension of collected washing machines?

As a representation of a circular ecosystem, a detailed value model in **Section 3.2** provided insight into how product, usage, and repair data sharing can contribute to the economic viability of extending the lifetime of collected washing machines and how much value each ecosystem actor adds. The elaborated value model explains that the lifetime extension of collected washing machines on a large scale is only possible if all washing machine ecosystem stakeholders are involved in a collective value proposition aiming for product lifetime extension.

2. Which requirements guide the development of a lifetime extension information system for collection agents and an assessment component in a 2030 scenario and the current situation?

The requirements for an information system for collection agents are based on working sessions with waste management experts, circular economy experts, and governments. In the requirements elicitation process, in the initial phase of the EngD study, much attention was paid to developing a system vision that clarifies which properties and functionalities a lifetime extension information system should have, according to the experts (see **Section 4.2**). In parallel, the case studies at organizations specializing in return evaluation processes and developed system solutions significantly contributed to this vision (see **Section 2.4**).

The initial focus of this EngD study was on product repair but gradually shifted to lifetime extension assessment because, according to the experts' opinions, the most significant impact can be achieved in the collection phase by assessing a large group of washing machines for possible lifetime extension and utilizing their possible value. Another critical consideration for the collection agent information system was the question of what a minimum acceptable residual life should be for washing machines that can be eligible for lifetime extension. Namely, a longer residual life affects the complexity of assessment and might require extensive product repair strategies leading to high costs that can surpass the initial list price of washing machines. Based on interviews with repairmen, the design choice was made that it should be possible to issue a minimum washing machine warranty of six months (see **Section 4.5**). A more extended warranty period would elicit more extensive overhaul and repair work.

After these critical design choices had been made, it was possible to trace back the requirements for the information system and assessment component for collection agents. Relevant requirements are related to select the highest possible circular strategy in the waste hierarchy, to realize a dynamic highly automated system that allows tailored-made decisions and assessment process routes, to enhance the system's self-learning ability to improve itself continuously, and to strive for transparency of lifetime extension assessments.

3. What are the envisioned design properties and functions of a future lifetime extension information system for collection agents supporting an objective assessment of collected washing machines?

The purpose of the information system designed for collection agents in this EngD study is to be able to make an informed binary decision based on data on the feasibility of extending the lifetime of collected washing machines. The information system consists of four components that communicate with each other via interfaces (see **Table 5-2**). The primary function of the system component that focuses on the registration of collected washing machines is to identify the returned washing machine and record its arrival at a collection agent. A connection can be made with product and usage information based on an unique identifier. A central DBMS facilitates the functions of data storage, integration, analytics, backup, and security management. An interface with washing machine DPPs in the cloud allows collection agents to extract data from and add data to the passport. A lifetime extension DSS facilitates collection agents in their informed decision-making. This subsystem enables data-driven assessment and supports subsequent judgments by applying an assessment component. The DSS has a user interface with an external lifetime extension application for employees of collection agents. The aggregated results of the lifetime extension assessment component are presented in a Business Intelligence visualization on dashboards that provides collection agents and governments with information on circular collection performance. The information system provides the digital environment in which the designed assessment component operates.

4. What are the design properties of a future lifetime extension assessment component?

The answer to this research question is based on the following sub-questions.

a. Which assessment criteria and data needs are critical when assessing collected washing machines for lifetime extension?

At the start of this EngD study, an attempt was made to formulate generic assessment criteria that can be applied to different EEE product categories. During this exploration, the complexity of this task became evident because the technical specifications per product category vary so greatly. In consultation with the client, the choice was therefore made to focus exclusively on washing machines in this study.

During the development of the lifetime extension assessment component, a comprehensive set of critical factors that influence any lifetime extension of washing machines was identified. Critical in the decision-making process is that the washing machines assessment should be time and cost-efficient. Consequently, the assessment process solely focuses on failure modes that are technically repairable, and possible repair costs should be in reasonable proportion to the original list price. Thus, the lifetime extension assessment component focuses exclusively on capital-intensive washing machines with a (relatively) high purchase value and product quality. Non-capital-intensive washing machines in the low-price segment are not worth repairing because product repair costs outweigh the initial list price.

Based on the scientific literature on product design and recovery of consumer electronics, repairability, life cycle assessment, and DPPs, critical lifetime extension assessment criteria were established in addition to interviews with repairers of washing machines. These assessment criteria provide insight into the data required to thoroughly assess collected washing machines for lifetime extension. Critical lifetime extension assessment factors can be traced back to product-related factors, washing machine health, the actors involved in the product lifecycle of a washing machine, environmental aspects, and the expected market demand (see **Section 6.2**).

b. What kind of data does a washing machine digital product passport for collection agents and other relevant stakeholders encompass to support informed decision-making?

During the design process it became clear that the DPP for washing machines does not only have a function for collection agents, but that it can also be a valuable decision-support instrument for consumers, recyclers, and governments. The DPP designed for washing machines in **Section 6.6** provides insight into which specific decision-support data are needed during the lifetime extension assessment of washing machines to be able to make informed decisions. The information category 'Washing Machine Product' is the backbone of the DPP. To support the technical lifetime extension assessment of washing machines, the information category 'Status, Diagnostics, and Current Performance' is relevant. Product and historical usage information provide a broad insight into the current status of a collected washing machine. It is assumed that by 2030 washing machines will be equipped with digital technologies, such as Internet-of-Things. Digitization enables data collection on the status of washing machines. The information category 'Value Chain Actors' enhances value transparency and clarifies value chain responsibilities. A future link with the materials passport also makes the origin of materials at suppliers transparent. According to Berger et al. (2022), the information category 'Sustainability and Circularity' assesses the environmental consequences of lifetime assessment. The information in this category can objectify the sustainable and circular claims of stakeholders in the washing machine ecosystem.

Validation sessions with collection agents, manufacturers, retailers, and repairers indicated that information about the washing machine product and its current status is perceived to be a priority. At the request of these respondents, additional information on parts and repairability has been included in the DPP. Information about the value chain, sustainability and circularity are of a lower priority in the short term for the respondents. Explorative research revealed that a considerable amount of data in the DPP for washing machines can be extracted from existing information sources, such as European

Product Registry for Energy Labelling. However, producers are reluctant to share this data with other stakeholders.

c. How can the data in the DPP support a generic assessment process to make an informed decision about possible lifetime extension of washing machines?

Section 6-7 provides a generic assessment process diagram for a 2030 scenario that explains how the designed DPP for washing machines supports lifetime extension assessment. The data in the DPP for washing machines are used for each process step, and corresponding data values are tested against assessment standards in a DSS. This EngD study assumes that all the desired data in a DPP are available and accessible and that collection agents have access to those data.

The designed assessment process is structured, for efficiency reasons, in such a way that assessment criteria that can be tested automatically based on data in the DPP, such as product characteristics, market demand, and technical diagnosis, are discussed first. Washing machines eligible for lifetime extension are visually inspected (manually or partially automated). Based on the data and assessment results in the previous steps, a preliminary diagnosis is made. Based on the preliminary diagnosis, an indicative technical, economic, and ecological estimation clarifies whether a washing machine is eligible for lifetime extension.

5. What are the design properties of a current lifetime extension assessment component with limited data accessibility?

This EngD study provides a validated assessment component for extending the lifetime of washing machines applicable to collection agents (see **Sections 7.4.2 and 7.4.3**). It is essential to ascertain that the designed assessment component reflects the present washing machine sector, and that it is not merely grafted onto lifetime extension and corresponding data sharing. Although specific product information (such as energy and water consumption) is stored in product manuals, this information has not been digitized in most cases. Consequently, many relevant assessment criteria, such as the number of washing machine cycles performed, year of manufacture, and list price, could not be incorporated into the assessment component. To find a solution for this design problem, derived secondary indicators were defined for the relevant assessment criteria in the assessment component, such as the brand and the visual condition of a washing machine. For each indicator, how the information could be obtained was investigated.

In consultation with the client, the decision was made to design a static assessment component for the current situation. Each assessment criterion is binary tested against a defined acceptance standard. If this acceptance standard has not been met, the assessment process ends. In the first phase of the assessment process, the focus is on generic assessment criteria. In a subsequent phase, visual assessment criteria guide the process.

This EngD study revealed that lifetime extension is mainly determined by the brand, the quality of bearings, and the physical condition of a washing machine. Firstly, repairers indicated that only German-brand washing machines are favorable for lifetime extension. Secondly, frequent failure modes such as defective motors, drums, tubs, bearings, and electronics are difficult to repair (Tecchio et al., 2019). According to repairers, the high costs of parts and labor for the key spare parts are usually disproportionate to the initial catalogue price of a washing machine. Thirdly, the completeness of the washing machine and its physical traits (such as dents and rust) determine whether a washing machine is eligible for lifetime extension. According to experts, the physical condition of a German brand washing machine has a greater predictive value than the age of the appliance. This can be explained by the fact that the age of a washing machine does not necessarily quantify its historical use.

Validation research concerning the assessment component revealed that the collection agents' configuration and attitude toward lifetime extension determine the extent to which they are inclined to select washing machines. This study has clarified that if a collection agent harvests parts and has repair facilities, they are more likely to select a washing machine for lifetime extension. Consequently, two assessment process routes were distinguished in the assessment component, allowing for differentiation in the answer categories. The validation tests of the assessment component prototype with a layperson clarified that some basic technical knowledge of washing machines is required, and that editing previous answers should be possible.

8.2 Contributions

8.2.1 Contribution to science

The WEEE industry has adopted circular principles to a limited extent (Bressanelli et al., 2020). The scientific literature's main focus is on WEEE management (Cesaro et al., 2018; Morris & Metternicht, 2016), Closed Loop Supply Chains (Coenen et al., 2018; Schenkel et al., 2015; Simonetto et al., 2022) and reverse logistics (Agrawal & Singh, 2019; Govindan & Bouzon, 2018; Islam & Huda, 2018) about the logistical features and conditions that are necessary to make the return process effective. The scientific body of knowledge on lifetime extension and the repairability of disposed of EEE has also grown in recent years (Bovea et al., 2016; Bracquene et al., 2021; Cordella et al., 2021), but much of this literature is focused on reduction and recycle strategies (Bressanelli, Saccani, Perona, et al., 2020). Limited attention has been paid to reuse and remanufacturing strategies. This study addresses a prominent research gap in the scientific literature concerning the circular trial assessment of discarded EEE for favorable reuse options enabling informed decision-making (Anandh et al., 2021). The main contribution of this EngD thesis is that the developed lifetime extension information system for collection agents and assessment components responds to this research gap by developing assessment methods allowing collection agents to make informed decisions about the possible lifetime extension of collected washing machines. The EngD thesis also contributes to the scientific DPP literature by designing a DPP for washing machines focusing on lifetime extension.

8.2.2 Contribution to governments

In the transition to a circular economy, governments have a policy-related, regulatory, and facilitating role. As noted in **Section 1.1**, the national government is actively steering its circular economy policy and related circular economy goals toward effective collection and lifetime extension of EEE in order to achieve the target of halving the consumption of raw materials by 2030 (Ministerie Infrastructuur & Waterstaat, 2022). With its Green Deal policies, the EU aims to improve the collection and treatment of discarded EEE, possibly in EU-wide take-back schemes (European Commission, 2019). It has become clear that most collected electronic devices are recycled, which means that preparation for reuse hardly occurs in the current WEEE management system, even though this reuse potential is present (Zacho et al., 2018).

This EngD study contributes to the local and national ambition of Dutch governments to collect discarded consumer electronics properly and set favorable conditions for lifetime extension to diminish the amount of E-waste. For this purpose, a lifetime extension information system for collection agents and data-driven assessment components has been developed. The generated assessment data of the designed assessment component facilitate governments to properly monitor and control the circular performances of collection agents.

8.2.3 Contribution to collection agents

As a contribution to a systemic transition to a circular economy, CirkelWaarde aims to utilize collected products and materials at the highest circular level. Exploring, recognizing, acknowledging, and retaining the residual value of collected consumer electronics is crucial in this respect. With this in mind, the E-novation Hub, as a joint expertise center, focuses on research into a systematized collection, evaluation and processing of discarded EEE. According to CirkelWaarde's partners, there are currently insufficient operational protocols and assessment instruments to help employees at collection points to systematize the process of receipt, intake, and determining appropriate circular reuse options, which depend on individually determined preferences. The generated assessment component in this EngD study provides CirkelWaarde with decision support instruments that will help them to assess collected washing machines for lifetime extension. The designed assessment components professionalize the current subjective assessment of collected washing machines by collection agent employees and offer favorable conditions for bridging the connection to promising second-hand markets.

8.3 Limitations

This section discusses the limitations concerning the development, design, and research of the system artifacts.

Biases

As is inherent to design science research, the construction of a completely transparent design process is challenging (Gregor & Hevner, 2013). With this in mind, design problems and system design decisions have been reported as transparently as possible, but biases have undoubtedly influenced the system development process.

Vision of future washing machine ecosystem

The detailed socio-technical scenarios outlined in this study have been a futuristic exercise in which many assumptions have been made. This study starts from the premise that macro developments (such as the EU Green Deal policies and geopolitical developments) and niche technological innovation, such as the use of DPPs and data sharing between stakeholders in the washing machine ecosystem, create favorable conditions for testing collected washing machines for extending their lifetime. However, although these assumptions are based on circular economy policy documents from governments and the scientific literature, it is unclear to what extent the recognized trends and developments will persist.

Value model

In an E3Value model, a 2030 scenario elaborated on how actors exchange value to clarify how changing stakeholder dynamics and value exchanges can benefit washing machine lifetime extension. However, the value model is based on many assumptions which may not become a reality, such as the assumption that value network actors act in a circular washing machine ecosystem where lifetime extension, information sharing, and economically viable value exchanges are fruitful.

Furthermore, the elaborated E3Value model should be approached as a transitional configuration. The model elaborates on the current situation but fails to introduce radical new actors (such as data analytics service providers, product service-oriented retailers, and new washing machine manufacturers producing washing machines from a circular product design perspective) who possibly might cause a radical disruption of the washing machine ecosystem to a fully circular ecosystem in which circular principles are applied at all stages of a washing machine's product lifecycle.

Information system architecture for collection agents

The envisioned lifetime extension information system architecture for collection agents should be approached as a conceptualization that clarifies the functionalities of such a system. The main goal of the system architecture is to explore how data-driven assessment of collected washing machines can contribute to informed decision-making regarding lifetime extension. Accordingly, the technology readiness level of the information system is limited. Validation of the information system by technology experts did not occur. Consequently, detailed interface design and subsystem specifications, such as the DBMS, are currently lacking.

Lifetime extension component and process, scenario 2030

As part of the lifetime extension component in a 2030 scenario, the designed DPP for washing machines has a mainly theoretical character. The DPP conceptualization presupposes full data availability and accessibility. Although the theoretical interaction between a lifetime extension assessment of discarded washing machines and the role of a DPP and DSS has been explored in a generic assessment process diagram, a practical demonstration that simulates a data-driven assessment has not yet been

conducted. Another limitation is that a DSS is included in a generic lifetime extension assessment process, but normative specifications are neglected.
Furthermore, digital technologies in washing machines enable continuous monitoring. Consequently, DPPs will have a dynamic character by 2030. The developed DPP contains a comprehensive set of information categories and properties, but it remains unclear whether additional dynamic properties should be defined in the DPP.

The practical feasibility of the information category "Sustainability and Circularity", is currently limited. As a contribution to a life cycle analysis, the desired quantitative assessment of the various properties requires critical choices with regard to assessment methods, calculation methods, inventory data, indicators and impact categories.

Data governance

The successful implementation of DPP for washing machines in circular ecosystems depends on systems integration and data governance aspects, such as product quality and data formats. However, due to the focus of this study, less attention has been paid to data governance principles.

Lifetime extension component and process: current situation

The designed assessment component only indicates whether lifetime extension of a collected washing machine is feasible or not. However, in a circular economy striving for long-term value retention of consumer electronics, extensive differentiation towards circular process routes in lifetime extension assessments is required (e.g., re-use, repair, overhaul, harvesting parts, or harvesting materials). Another limitation is that this study focuses solely on washing machines. The application of the assessment component to other EEE product categories has not been investigated.

The actual implementation of the assessment component has not yet taken place, meaning that the generalizability of the study results is currently limited. The validation of the lifetime extension assessment component in the current situation using a single case mechanism experiment with a relatively small sample of discarded washing machines occurred at only two collection agents in the Netherlands. Consequently, the sensitivity of the assessment component for different contexts is limited. In the research conducted at the two collection centers, experts were affected by their confirmation bias due to their extensive product knowledge and experience of assessing washing machines for lifetime extension. Another limitation is that the current lifetime extension assessment component only focuses on German washing machine brands and does not consider other brands.

Validation of assessment component by layperson

During the development process, the cognitive and linguistic competencies required by the prototype of the assessment component did not sufficiently match the competencies of actual collection agent employees. Therefore, only highly educated layperson validated the lifetime extension assessment component, and, consequently, the designed assessment component has not yet been tested among a wider sample of collection agent employees.

8.4 Future work

8.4.1 Recommendations for collection agents

In line with the elaborated migration plan in **Section 7.5**, the following practical recommendations for collection agents have been defined:

Testing lifetime extension assessment component on a larger scale

An essential first step for collection agents will be to test the effectiveness of the lifetime assessment component on a larger scale in the collection and assessment of washing machines. The analytical insights generated by this validation will provide collection agents insight into the characteristics of collected washing machines, how many appliances are approved and rejected, and clarify which assessment criteria washing machines may have been rejected on.

Optimizing current operational collection process activities

The assessment component helps collection agents to collect and assess discarded washing machines more critically from a lifetime extension perspective. However, the success of the assessment component strongly depends on its embedding in the logistics and operational processes of collection agents. Therefore, collectors are requested to improve the effectiveness of their logistics and operational collection process activities to support the lifetime extension assessment. Careful handling of the supplied washing machine, the design of a collection location, and digital tools for employees to carry out the lifetime extension assessment contribute to this.

Premature automation initiatives

The envisioned data-driven assessment of collected washing machines by applying DPPs and digital technologies in washing machines requires collection agents to anticipate this development at an early stage. The digitalization and datafication of collected washing machines contribute to a high-quality assessment but require reconsidering the collection process's logistics handling and operations management. Therefore, collection agents should initiate automation initiatives at an early stage, such as product scanners to identify a washing machine at intake, a DBMS, an automated lifetime extension DSS that supports employees in the assessment process, and dashboards that display circular performance to implement the automation process.

8.4.2 Research outlook

Based on the limitations in the previous section, the following future research activities emerge:

Circular washing machine ecosystems

Future research should focus on the specific configurations of circular ecosystems in the context of the lifetime extension of consumer electronics. Empirical studies should clarify how specific elements of circular ecosystems are implemented. For example, the orchestration of the ecosystem actors, the collective circular value proposition that the circular ecosystem co-creates, the role of a collector within the ecosystem, how resources are shared in the circular ecosystem (e.g., sharing data), how digital technologies are utilized to create value, and what role governance plays in supporting coordination and value sharing among ecosystem actors.

Economic viability of a circular washing machine ecosystem

Future research should provide insight into quantifying value activities among actors in the washing machine ecosystem. Modelling a net value stream analysis of the value activities in the E3value software application is likewise advisable. Such quantification of the value model would provide an understanding of the economic viability of a circular ecosystem.

Lifetime extension information system for collection agents

The lifetime extension information system developed for collection agents requires considerable concretization of its major subsystems and their interactions. Further research should elaborate on the structure, behaviors, and views of the lifetime extension information system for collection agents. With this in mind, integration solutions to connect IT systems across the washing machine ecosystem, which contribute to the information system's overall performance, should be addressed. According to Götz et al. (2022), digital infrastructure and software for the IT implementation of DPP require interoperability and compatibility with other systems. Therefore, possible software architecture solutions that facilitate integration and interoperability in the EEE circular ecosystem should be explored, for example, service-oriented architecture solutions. This requires research into aspects of data governance regarding the setting of data policies that clarify which quality requirements the data in the DPPs must meet in order to enable data sharing, integration, and integrity across the washing machine ecosystem. Preferably, the DPP for washing machines will be integrated into existing information systems. Research should clarify potential information sources for supplying the DPP with data, such as the European Product Registry on Energy Labelling. Follow-up research should also clarify each EEE value chain actor's DPP rights, such as access rights, editing rights, and rights to add data. Further research should also clarify which drivers, enablers, and barriers influence the successful implementation of DPPs for washing machines.

Demonstration of lifetime assessment component

In future research, a prototype of the developed assessment component and process, including the future scenario functions, should be fed with artificial product and usage data on collected washing machines to monitor the system behaviors, to evaluate its predictive value and to analyze possible differences. The DPP's information categories and properties must be enriched with actual data values. Also, the acceptance standards in the DSS should be specified, whereupon the data-driven assessment of washing machines and the operation of the DPP can be simulated. A sensitivity analysis can clarify to what extent the research results are affected by a change in the acceptance standards in the DSS. Waste management and technology experts should observe the system behaviors and the degree to which the system solutions are generalizable to collection agents and other washing machine ecosystem players. As such, validation of the lifetime extension assessment component with multiple collection agents is necessary to determine to what extent their unique collection configurations align sufficiently with the designed assessment component. Several washing machine brands, product types, and a substantial quantity of washing machines should be involved in the sample to critically test the external validity and reliability of the assessment component. Other EEE products, such as dishwashers and vacuum cleaners, would necessarily be included to enable lifetime extension on a larger scale. Therefore, additional research is required to determine to what extent the information categories and properties in the DPP for washing machines might also apply to other EEE product categories.

Usability assessment component

Another consideration is that future research should focus on the validation of the lifetime extension assessment component by employees of collection agents. Implementing the lifetime extension assessment component in the current situation depends on its usability. Given the language level and the cognitive ability of collection agent employees, research should provide insights into user requirements and the consequences of designing and presenting the information in the assessment component. For this purpose, the application of usability testing methods should measure a wide variety of usability indicators among employees.

Acknowledgements

From a business background, the professional transition into the IT-domain has brought me tremendous joy and spirit over the past years. The journey and success of this EngD endeavor would not have been possible without the support of my supervisors. The supervision by the University of Twente's esteemed professors Marten van Sinderen and Luiz Olavo Bonino da Silva Santos from the Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS), Services, Cybersecurity & Safety (SCS) has been crucial for my introduction to the domain of Information technology and Data. My sincerest thanks go out to you both! I am also thankful to Program Director EngD Business & IT Luís Ferreira Pires of the University of Twente for his encouragement in applying for the EngD-BIT program.

As driving forces in the E-novation Hub, I'm extremely grateful to Marjolein Mann of ROVA and Michiel Westerhoff of CircuLeer. Your extensive knowledge of Waste Management and Circular Economy was priceless and significantly contributed to my expertise concerning the lifetime extension of collected consumer electronics. Major thanks also to the E-novation Hub partners for sharing knowledge about collecting and repairing discarded consumer electronics. During the EngD project, many organizations were willing to welcome me for conducting my research activities. Thank you so much for sharing your expertise with me.

My EngD project closely relates to the knowledge topics of circular innovation and digitization that Saxion has defined in its strategic knowledge agenda. I'm blessed with the opportunities Saxion has offered me. Director Karin Verschoor of the School of Commerce and professor Michiel Flooren of the Regional Development lectorship, thank you so much for everything! Your support, dedication and kindness boosted my career and personal professional development. I'd also like to express my sincere gratitude to Cindy Kuiper and Hans Vossensteyn of the Saxion Research & Graduate School for initiating and supporting my EngD trajectory.

My sincerest thanks go out to my immediate family for their unwavering support during the EngD process. Their continuous encouragements to push my limits has been instrumental to my work. Special thanks go to my Saxion colleague, EngD student, and friend Evelyn Tempel. Your perseverance, kindness, and friendship stimulated me immensely. Last but not least, I'm extremely grateful to my friends for their unconditional support during my EngD journey. Thank you Miranda, Robert, Edith, Trudie, Anne, Delilah, Eddie, Peter, and Anouk. You rock!

References

Abraham, R., Schneider, J., & Vom Brocke, J. (2019). Data governance: A conceptual framework, structured review, and research agenda. *International Journal of Information Management*, *49*, 424-438.

Adisorn, T., Tholen, L., & Götz, T. (2021). Towards a digital product passport fit for contributing to a circular economy. *Energies*, *14*(8), 2289.

Agrawal, S., & Singh, R. K. (2019). Analyzing disposition decisions for sustainable reverse logistics: Triple Bottom Line approach. *Resources, conservation and recycling*, *150*, 104448.

Aheleroff, S., Xu, X., Lu, Y., Aristizabal, M., Velásquez, J. P., Joa, B., & Valencia, Y. (2020). IoT-enabled smart appliances under industry 4.0: A case study. *Advanced engineering informatics*, *43*, 101043.

Al-Salem, S. M., Leeke, G. A., El-Eskandarany, M. S., Van Haute, M., Constantinou, A., Dewil, R., & Baeyens, J. (2022). On the implementation of the circular economy route for E-waste management: A critical review and an analysis for the case of the state of Kuwait. *Journal of Environmental Management*, *323*, 116181.

Alaa, M., Zaidan, A. A., Zaidan, B. B., Talal, M., & Kiah, M. L. M. (2017). A review of smart home applications based on Internet of Things. *Journal of Network and Computer Applications*, *97*, 48-65.

Alcalde-Calonge, A., Sáez-Martínez, F. J., & Ruiz-Palomino, P. (2022). Evolution of research on circular economy and related trends and topics. A thirteen-year review. *Ecological Informatics*, 101716.

Aldea, A., Iacob, M. E., van Hillegersberg, J., Quartel, D., & Franken, H. (2015). Modelling value with archimate. International Conference on Advanced Information Systems Engineering,

Aldea, A., Kusumaningrum, M. C., Iacob, M. E., & Daneva, M. (2018). Modeling and analyzing digital business ecosystems: An approach and evaluation. 2018 IEEE 20th Conference on Business Informatics (CBI),

Alejandre, C., Akizu-Gardoki, O., & Lizundia, E. (2022). Optimum operational lifespan of household appliances considering manufacturing and use stage improvements via life cycle assessment. *Sustainable Production and Consumption*, *32*, 52-65.

Alfieri, F., Cordella, M., Stamiminger, R., & Bues, A. (2018). Durability assessment of products: analysis and testing of washing machines. *Report EUR 29487 EN*.

Aminoff, A., & Sundqvist-Andberg, H. (2021). Constraints leading to system-level lock-ins—the case of electronic waste management in the circular economy. *Journal of Cleaner Production*, *322*, 129029.

Anandh, G., PrasannaVenkatesan, S., Goh, M., & Mathiyazhagan, K. (2021). Reuse assessment of WEEE: Systematic review of emerging themes and research directions. *Journal of Environmental Management*, *287*, 112335.

Antikainen, M., Uusitalo, T., & Kivikytö-Reponen, P. (2018). Digitalisation as an enabler of circular economy. *Procedia Cirp*, *73*, 45-49.

Ardente, F., & Mathieux, F. (2014). Environmental assessment of the durability of energy-using products: method and application. *Journal of Cleaner Production*, *74*, 62-73.

Bakker, C. A., Den Hollander, M., Van Hinte, E., & Zijlstra, Y. (2014). *Products that last: Product design for circular business models*. TU Delft Library.

Berger, K., Schöggl, J.-P., & Baumgartner, R. J. (2022). Digital battery passports to enable circular and sustainable value chains: Conceptualization and use cases. *Journal of Cleaner Production*, *353*, 131492.

Bertassini, A. C., Zanon, L. G., Azarias, J. G., Gerolamo, M. C., & Ometto, A. R. (2021). Circular Business Ecosystem Innovation: A guide for mapping stakeholders, capturing values, and finding new opportunities. *Sustainable Production and Consumption*, *27*, 436-448.

Bocken, N., & Ritala, P. (2021). Six ways to build circular business models. *Journal of Business Strategy*.

Bocken, N. M., De Pauw, I., Bakker, C., & Van Der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of industrial and production engineering*, *33*(5), 308-320.

Börner, L., & Hegger, D. L. (2018). Toward design principles for sound e-waste governance: A research approach illustrated with the case of the Netherlands. *Resources, conservation and recycling*, *134*, 271-281.

Bovea, M. D., Ibáñez-Forés, V., Juan, P., Pérez-Belis, V., & Braulio-Gonzalo, M. (2018). Variables that affect the environmental performance of small electrical and electronic equipment. Methodology and case study. *Journal of Cleaner Production*, *203*, 1067-1084.

Bovea, M. D., Ibáñez-Forés, V., & Pérez-Belis, V. (2020). Repair vs. replacement: Selection of the best end-of-life scenario for small household electric and electronic equipment based on life cycle assessment. *Journal of Environmental Management*, *254*, 109679.

Bovea, M. D., Ibáñez-Forés, V., Pérez-Belis, V., & Quemades-Beltrán, P. (2016). Potential reuse of small household waste electrical and electronic equipment: methodology and case study. *Waste Management*, *53*, 204-217.

Boyano, A., Cordella, M., Epinosa, N., Villanueva, A., Graulich, K., Rudenauer, I., Alborzi, F., Hook, I., & Stamminger, R. (2017). *Ecodesign and Energy Label for Household Washing machines and washer dryers*.

Bracquené, E., Brusselaers, J., Dams, Y., Peeters, J., De Schepper, K., Duflou, J., & Dewulf, W. (2018). Repairability criteria for energy related products. *Study in the BeNeLux Context to Evaluate the Options to Extend the Product Life Time Final Report*.

Bracquene, E., Peeters, J., Alfieri, F., Sanfelix, J., Duflou, J., Dewulf, W., & Cordella, M. (2021). Analysis of evaluation systems for product repairability: A case study for washing machines. *Journal of Cleaner Production*, *281*, 125122.

Bressanelli, G., Perona, M., & Saccani, N. (2017). Reshaping the washing machine industry through circular economy and product-service system business models. *Procedia Cirp*, *64*, 43-48.

Bressanelli, G., Perona, M., & Saccani, N. (2019). Challenges in supply chain redesign for the Circular Economy: A literature review and a multiple case study. *International Journal of Production Research*, *57*(23), 7395-7422.

Bressanelli, G., Saccani, N., Perona, M., & Baccanelli, I. (2020). Towards circular economy in the household appliance industry: An overview of cases. *Resources*, *9*(11), 128.

Bressanelli, G., Saccani, N., Pigosso, D. C., & Perona, M. (2020). Circular Economy in the WEEE industry: A systematic literature review and a research agenda. *Sustainable Production and Consumption*, *23*, 174-188.

Bryson, J. M. (2003). What to do when stakeholders matter: A guide to stakeholder identification and analysis techniques. *A paper presented at the London School of Economics and Political Science*, *10*, 2003.

Cesaro, A., Marra, A., Kuchta, K., Belgıorno, V., & Van Hullebusch, E. D. (2018). WEEE management in a circular economy perspective: An overview. *Glob. Nest J*, *20*, 743-750.

Chen, J., Sun, L., & Guo, H. (2017). Product carbon footprint assessment supporting the green supply chain construction in household appliance manufacturers. IOP Conference Series: Earth and Environmental Science, Coenen, J., Van der Heijden, R. E., & van Riel, A. C. (2018). Understanding approaches to complexity and uncertainty in closed-loop supply chain management: Past findings and future directions. *Journal of Cleaner Production*, *201*, 1-13.

Commission, E. (2019). *Circular economy action plan - for a cleaner and more competitive Europe*. Brussels: European Commission Retrieved from https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

Commission, E. (2021). *Proposal for a regulation of the European parliament and of the council establishing a carbon border adjustment mechanism*. Brussels Retrieved from https://eur-lex.europa.eu/resource.html?uri=cellar:a95a4441-e558-11eb-a1a5-01aa75ed71a1.0001.02/DOC_1&format=PDF

Cordella, M., Alfieri, F., Clemm, C., & Berwald, A. (2021). Durability of smartphones: A technical analysis of reliability and repairability aspects. *Journal of Cleaner Production*, *286*, 125388.

Cordella, M., Alfieri, F., & SANFELIX, F. J. V. (2019). Analysis and development of a scoring system for repair and upgrade of products.

Cordella, M., Sanfelix, J., & Alfieri, F. (2018). Development of an Approach for Assessing the Reparability and Upgradability of Energy-related Products. *Procedia Cirp*, *69*, 888-892.

Cramer, J. (2022). Effective governance of circular economies: An international comparison. *Journal of Cleaner Production*, *343*, 130874.

Daou, A., Mallat, C., Chammas, G., Cerantola, N., Kayed, S., & Saliba, N. A. (2020). The Ecocanvas as a business model canvas for a circular economy. *Journal of Cleaner Production*, *258*, 120938.

De Wit, M. (2022). The Circularity Gap Report 2022. In L. Haigh (Ed.), *Five years of analysis and insights*. Amsterdam.

Den Hollander, M. C., Bakker, C. A., & Hultink, E. J. (2017). Product design in a circular economy: Development of a typology of key concepts and terms. *Journal of Industrial Ecology*, *21*(3), 517-525.

Elzinga, R., Reike, D., Negro, S. O., & Boon, W. P. (2020). Consumer acceptance of circular business models. *Journal of Cleaner Production*, *254*, 119988.

Ertz, M., Leblanc-Proulx, S., Sarigöllü, E., & Morin, V. (2019). Made to break? A taxonomy of business models on product lifetime extension. *Journal of Cleaner Production*, *234*, 867-880.

Ertz, M., Sun, S., Boily, E., Kubiat, P., & Quenum, G.-G.-Y. (2022a). How transitioning to Industry 4.0 promotes circular product lifetimes. *Industrial Marketing Management*, *101*, 125-140.

Ertz, M., Sun, S., Boily, E., Kubiat, P., & Quenum, G. G. Y. (2022b). How transitioning to Industry 4.0 promotes circular product lifetimes. *Industrial Marketing Management*, *101*, 125-140.

Flipsen, B., Bakker, C., & van Bohemen, G. (2016). Developing a reparability indicator for electronic products. 2016 Electronics Goes Green 2016+(EGG),

Fontana, A., Barni, A., Leone, D., Spirito, M., Tringale, A., Ferraris, M., Reis, J., & Goncalves, G. (2021). Circular economy strategies for equipment lifetime extension: A systematic review. *Sustainability*, *13*(3), 1117.

Forti, V., Balde, C. P., Kuehr, R., & Bel, G. (2020). The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential.

Freeman, R. E. (1994). The politics of stakeholder theory: Some future directions. *Business ethics quarterly*, 409-421.

Geels, F. W. (2005). The dynamics of transitions in socio-technical systems: a multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). *Technology analysis & strategic management*, *17*(4), 445-476.

Geisendorf, S., & Pietrulla, F. (2018). The circular economy and circular economic concepts—a literature analysis and redefinition. *Thunderbird International Business Review*, *60*(5), 771-782.

Geissdoerfer, M., Morioka, S. N., de Carvalho, M. M., & Evans, S. (2018). Business models and supply chains for the circular economy. *Journal of Cleaner Production*, *190*, 712-721.
Geissdoerfer, M., Pieroni, M. P., Pigosso, D. C., & Soufani, K. (2020). Circular business models: A review. *Journal of Cleaner Production*, *277*, 123741.
Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The Circular Economy–A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757-768.
Ghisellini, P., Ripa, M., & Ulgiati, S. (2018). Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. *Journal of Cleaner Production*, *178*, 618-643.
Ghisellini, P., & Ulgiati, S. (2020). Managing the transition to the circular economy. In *Handbook of the circular economy* (pp. 491-504). Edward Elgar Publishing.
Ghoreishi, M., & Happonen, A. (2020). New promises AI brings into circular economy accelerated product design: A review on supporting literature. E3S web of conferences,
Gomes, G. M., Moreira, N., & Ometto, A. R. (2022). Role of consumer mindsets, behaviour, and influencing factors in circular consumption systems: A systematic review. *Sustainable Production and Consumption*.
Gordijn, J. (2004). E-business value modelling using the e3-value ontology. In *Value creation from e-business models* (pp. 98-127). Elsevier.
Götz, T., Berg, H., Jansen, M., Adisorn, T., Cembrero, D., Markkanen, S., & Chowdhury, T. (2022). Digital product passport: the ticket to achieving a climate neutral and circular European economy?
Govindan, K., & Bouzon, M. (2018). From a literature review to a multi-perspective framework for reverse logistics barriers and drivers. *Journal of Cleaner Production*, *187*, 318-337.
Govindan, K., & Soleimani, H. (2017). A review of reverse logistics and closed-loop supply chains: a Journal of Cleaner Production focus. *Journal of Cleaner Production*, *142*, 371-384.
Grafström, J., & Aasma, S. (2021). Breaking circular economy barriers. *Journal of Cleaner Production*, *292*, 126002.
Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. *MIS quarterly*, 337-355.
Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future generation computer systems*, *29*(7), 1645-1660.
Gülserliler, E. G., Blackburn, J. D., & Van Wassenhove, L. N. (2022). Consumer acceptance of circular business models and potential effects on economic performance: The case of washing machines. *Journal of Industrial Ecology*, *26*(2), 509-521.
Guzzo, D., Rodrigues, V. P., & Mascarenhas, J. (2021). A systems representation of the Circular Economy: transition scenarios in the electrical and electronic equipment (EEE) industry. *Technological Forecasting and Social Change*, *163*, 120414.
Hauthal, H. G. (2012). Washing at Low Temperatures–Saving Energy, Ensuring Hygiene. *Tenside Surfactants Detergents*, *49*(2), 171-177.
Hedberg, A., & Šipka, S. (2021). Toward a circular economy: The role of digitalization. *One Earth*, *4*(6), 783-785.
Hennies, L., & Stamminger, R. (2016). An empirical survey on the obsolescence of appliances in German households. *Resources, conservation and recycling*, *112*, 73-82.
Hevner, A. R. (2007). A three cycle view of design science research. *Scandinavian journal of information systems*, *19*(2), 4.
Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS quarterly*, 75-105.

Hofman, P. S., & Elzen, B. (2010). Exploring system innovation in the electricity system through sociotechnical scenarios. *Technology analysis & strategic management*, *22*(6), 653-670.
Huttunen, S., Ojanen, M., Ott, A., & Saarikoski, H. (2022). What about citizens? A literature review of citizen engagement in sustainability transitions research. *Energy Research & Social Science*, *91*, 102714.
Indicators, C. (2016). Circularity Indicators: Project Introduction. Ellen MacArthur Foundation. In: Granta and Life [referenced 8. August 2016]. Available in: https://emfpacks ….
Initiative, S. (2014). Solving the e-waste problem (step) white paper: one global definition of e-waste. *Bonn, Germany*. *Step*, *3576*.
Islam, M. T., & Huda, N. (2018). Reverse logistics and closed-loop supply chain of Waste Electrical and Electronic Equipment (WEEE)/E-waste: A comprehensive literature review. *Resources, conservation and recycling*, *137*, 48-75.
Jaeger-Erben, M., Frick, V., & Hipp, T. (2021). Why do users (not) repair their devices? A study of the predictors of repair practices. *Journal of Cleaner Production*, *286*, 125382.
Jaiswal, A., Samuel, C., Patel, B. S., & Kumar, M. (2015). Go green with WEEE: Eco-friendly approach for handling e-waste. *Procedia Computer Science*, *46*, 1317-1324.
Johnson, M., Fitzpatrick, C., Wagner, M., & Huisman, J. (2018). Modelling the levels of historic waste electrical and electronic equipment in Ireland. *Resources, conservation and recycling*, *131*, 1-16.
Johnson, M., McMahon, K., & Fitzpatrick, C. (2020). A preparation for reuse trial of washing machines in Ireland. *Sustainability*, *12*(3), 1175.
Josey, A. (2017). *ArchiMate® 3.0. 1-A pocket guide*. Van Haren.
Josey, A. (2018). *The TOGAF® Standard, Version 9.2-A Pocket Guide*. Van Haren.
Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., & Hekkert, M. (2018). Barriers to the circular economy: Evidence from the European Union (EU). *Ecological economics*, *150*, 264-272.
Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, conservation and recycling*, *127*, 221-232.
Kirchherr, J., & van Santen, R. (2019). Research on the circular economy: A critique of the field. *Resources, conservation and recycling*, *151*.
Konietzko, J., Bocken, N., & Hultink, E. J. (2020). Circular ecosystem innovation: An initial set of principles. *Journal of Cleaner Production*, *253*, 119942.
Köseoğlu, M. N. (2022). From the ideal to the reality: How to operationalise an impactful Circular Economy transition? *Geoforum*.
Krämer, L. (2020). Planning for climate and the environment: the EU green deal. *Journal for European Environmental & Planning Law*, *17*(3), 267-306.
Kumar, A., Holuszko, M., & Espinosa, D. C. R. (2017). E-waste: An overview on generation, collection, legislation and recycling practices. *Resources, conservation and recycling*, *122*, 32-42.
Lee, I. (2019). The Internet of Things for enterprises: An ecosystem, architecture, and IoT service business model. *Internet of Things*, *7*, 100078.
Leiting, A.-K., De Cuyper, L., & Kauffmann, C. (2022). The Internet of Things and the case of Bosch: Changing business models while staying true to yourself. *Technovation*, *118*, 102497.
Luthin, A., Traverso, M., & Crawford, R. H. (2023). Assessing the social life cycle impacts of circular economy. *Journal of Cleaner Production*, *386*, 135725.
MacArthur, E. (2013). Towards the circular economy. *Journal of Industrial Ecology*, *2*(1), 23-44.
Mboli, J. S., Thakker, D., & Mishra, J. (2022). An IoT-enabled Decision Support System for Circular Economy Business Model.
Mellal, M. A. (2020). Obsolescence–A review of the literature. *Technology in Society*, *63*, 101347.

Mies, A., & Gold, S. (2021). Mapping the social dimension of the circular economy. *Journal of Cleaner Production*, *321*, 128960.
Milani, A., Camarda, C., & Savoldi, L. (2015). A simplified model for the electrical energy consumption of washing machines. *Journal of Building Engineering*, *2*, 69-76.
Ministerie Infrastructuur & Milieu. (2016). *Nederland Circulair 2050*. Den Haag Retrieved from https://www.rijksoverheid.nl/onderwerpen/circulaire-economie/documenten/rapporten/2016/09/14/bijlage-1-nederland-circulair-in-2050
Ministerie Infrastructuur & Waterstaat. (2022). *Adviesroute naar een circulaire economie voor consumptiegoederen.* . Den Haag: Ministerie Infrastructuur & Waterstaat Retrieved from https://www.rijksoverheid.nl/documenten/rapporten/2022/07/15/bijlage-3-adviesroute-naar-een-circulaire-economie-voor-consumptiegoederen
Ministerie van Buitenlandse Zaken. (2023). *Duurzaamheidsverslag 2022, Walk our Talk*. Den Haag Retrieved from file:///C:/Users/fst06/Downloads/230516_BuZa_Duurzaamheidsverslag_FINAL.pdf
Moreno, M., De los Rios, C., Rowe, Z., & Charnley, F. (2016). A conceptual framework for circular design. *Sustainability*, *8*(9), 937.
Morris, A., & Metternicht, G. (2016). Assessing effectiveness of WEEE management policy in Australia. *Journal of Environmental Management*, *181*, 218-230.
Neves, S. A., & Marques, A. C. (2022). Drivers and barriers in the transition from a linear economy to a circular economy. *Journal of Cleaner Production*, *341*, 130865.
Nham, N. T. H. (2022). Making the circular economy digital or the digital economy circular? Empirical evidence from the European region. *Technology in Society*, *70*, 102023.
Nussholz, J. L. (2018). A circular business model mapping tool for creating value from prolonged product lifetime and closed material loops. *Journal of Cleaner Production*, *197*, 185-194.
Okumura, S. (2022). Reuse-efficiency model for evaluating circularity of end-of-life products. *Computers & Industrial Engineering*, *171*, 108232.
Omer, A. M. (2009). Energy use and environmental impacts: A general review. *Journal of renewable and Sustainable Energy*, *1*(5), 053101.
Padilla-Rivera, A., Russo-Garrido, S., & Merveille, N. (2020). Addressing the social aspects of a circular economy: A systematic literature review. *Sustainability*, *12*(19), 7912.
Pakula, C., & Stamminger, R. (2015). Energy and water savings potential in automatic laundry washing processes. *Energy Efficiency*, *8*, 205-222.
Palm, J., & Bocken, N. (2021). Achieving the circular economy: Exploring the role of local governments, business and citizens in an urban context. In (Vol. 14, pp. 875): MDPI.
Pan, X., Wong, C. W., & Li, C. (2022). Circular economy practices in the waste electrical and electronic equipment (WEEE) industry: A systematic review and future research agendas. *Journal of Cleaner Production*, 132671.
Park, P.-J., Lee, K.-M., & Wimmer, W. (2006). Development of an environmental assessment method for consumer electronics by combining top-down and bottom-up approaches (11 pp). *The international journal of life cycle assessment*, *11*, 254-264.
Patwa, N., Sivarajah, U., Seetharaman, A., Sarkar, S., Maiti, K., & Hingorani, K. (2021). Towards a circular economy: An emerging economies context. *Journal of business research*, *122*, 725-735.
PBL Plan Bureau Leefomgeving. (2019). *Doelstelling Circulaire Economie 2030 - Operationalisering, concretisering en reflectie*. Den Haag: Plan Bureau Leefomgeving Retrieved from https://open.overheid.nl/repository/ronl-9dbb891a-27a2-42b1-80be-71b9212af833/1/pdf/bijlage-1-pbl-2019-policy-brief-doelstelling-circulaire-economie-2030-3551.pdf

Peeters, J., Sterkens, W., Bracquene, E., Ramon, H., & Dewulf, W. (2021). Software applications adopting computer vision for repair, reuse and recycling. 2019 PLATE Conference Proceedings,

Peiró, L. T., Baiguera, F., Maci, A., Olivieri, M., Villa, P., Colledani, M., & i Durany, X. G. (2021). Digitalization as an enabler of the Circular Economy of electronics. *Procedia Manufacturing*, *54*, 58-63.

Persson, O., & Hinton, J. B. (2023). Second-hand clothing markets and a just circular economy? Exploring the role of business forms and profit. *Journal of Cleaner Production*, *390*, 136139.

Pieroni, M. P., McAloone, T. C., & Pigosso, D. C. (2021). Circular economy business model innovation: Sectorial patterns within manufacturing companies. *Journal of Cleaner Production*, *286*, 124921.

Pires, A., & Martinho, G. (2019). Waste hierarchy index for circular economy in waste management. *Waste Management*, *95*, 298-305.

Plociennik, C., Pourjafarian, M., Nazeri, A., Windholz, W., Knetsch, S., Rickert, J., Ciroth, A., Lopes, A. d. C. P., Hagedorn, T., & Vogelgesang, M. (2022). Towards a Digital Lifecycle Passport for the Circular Economy. *Procedia Cirp*, *105*, 122-127.

Plotkin, D. (2020). *Data stewardship: An actionable guide to effective data management and data governance*. Academic Press.

Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). Circular economy: measuring innovation in the product chain. *Planbureau voor de Leefomgeving*(2544).

Prakash, S., Dehoust, G., Gsell, M., Schleicher, T., & Stamminger, R. (2020). *Influence of the service life of products in terms of their environmental impact: Establishing an information base and developing strategies against" obsolescence"*. Umweltbundesamt.

Ranta, V., Aarikka-Stenroos, L., & Väisänen, J.-M. (2021). Digital technologies catalyzing business model innovation for circular economy—Multiple case study. *Resources, conservation and recycling*, *164*, 105155.

Rautela, R., Arya, S., Vishwakarma, S., Lee, J., Kim, K.-H., & Kumar, S. (2021). E-waste management and its effects on the environment and human health. *Science of the Total Environment*, *773*, 145623.

REPAIR.EU. (2021, 3 February 2021). *The French repair index: challenges and opportunities*. https://repair.eu/news/the-french-repair-index-challenges-and-opportunities/

Rizos, V., & Bryhn, J. (2022). Implementation of circular economy approaches in the electrical and electronic equipment (EEE) sector: Barriers, enablers and policy insights. *Journal of Cleaner Production*, *338*, 130617.

Saari, L., Heilala, J., Heikkilä, T., Kääriäinen, J., Pulkkinen, A., & Rantala, T. (2022). Digital product passport promotes sustainable manufacturing: whitepaper.

Saarikko, T., Westergren, U. H., & Blomquist, T. (2017). The Internet of Things: Are you ready for what's coming? *Business Horizons*, *60*(5), 667-676.

Sabbaghi, M., Cade, W., Behdad, S., & Bisantz, A. M. (2017). The current status of the consumer electronics repair industry in the US: A survey-based study. *Resources, conservation and recycling*, *116*, 137-151.

Safdar, N., Khalid, R., Ahmed, W., & Imran, M. (2020). Reverse logistics network design of e-waste management under the triple bottom line approach. *Journal of Cleaner Production*, *272*, 122662.

Sales, T. P. (2019). *Ontological Foundations for Strategic Business Modeling: The Case of Value, Risk and Competition* University of Trento].

Sari, D. P., Masruroh, N. A., & Asih, A. M. S. (2021). Consumer intention to participate in e-waste collection programs: A study of smartphone waste in Indonesia. *Sustainability*, *13*(5), 2759.

Sassanelli, C., Rosa, P., Rocca, R., & Terzi, S. (2019). Circular economy performance assessment methods: A systematic literature review. *Journal of Cleaner Production*, *229*, 440-453.

Savage, G. T., Nix, T. W., Whitehead, C. J., & Blair, J. D. (1991). Strategies for assessing and managing organizational stakeholders. *Academy of management perspectives*, *5*(2), 61-75.
Schenkel, M., Caniëls, M. C., Krikke, H., & van der Laan, E. (2015). Understanding value creation in closed loop supply chains–Past findings and future directions. *Journal of Manufacturing Systems*, *37*, 729-745.
Shah, K., Patel, N., Thakkar, J., & Patel, C. (2022). Exploring applications of blockchain technology for Industry 4.0. *Materials Today: Proceedings*, *62*, 7238-7242.
Simonetto, M., Sgarbossa, F., Battini, D., & Govindan, K. (2022). Closed loop supply chains 4.0: From risks to benefits through advanced technologies. A literature review and research agenda. *International Journal of Production Economics*, 108582.
Spanaki, K., Karafili, E., & Despoudi, S. (2022). Digital architectures: frameworks for supply chain data and information governance. In *The Digital Supply Chain* (pp. 147-161). Elsevier.
Stahel, W. R. (2016). The circular economy. *Nature*, *531*(7595), 435-438.
Stamminger, R., Bues, A., Alfieri, F., & Cordella, M. (2020). Durability of washing machines under real life conditions: Definition and application of a testing procedure. *Journal of Cleaner Production*, *261*, 121222.
Stamminger, R., Tecchio, P., Ardente, F., Mathieux, F., & Niestrath, P. (2018). Towards a durability test for washing-machines. *Resources, conservation and recycling*, *131*, 206-215.
Stichting Open. (2022). *Nationaal (W)EEE Register*. Zoeterwoude Retrieved from file:///C:/Users/fst06/Downloads/NWR-20220627-Rapportage-2021.pdf
Suppatvech, C., Godsell, J., & Day, S. (2019). The roles of internet of things technology in enabling servitized business models: A systematic literature review. *Industrial Marketing Management*, *82*, 70-86.
Tecchio, P., Ardente, F., & Mathieux, F. (2019). Understanding lifetimes and failure modes of defective washing machines and dishwashers. *Journal of Cleaner Production*, *215*, 1112-1122.
Terpstra, P. (2001). Assessment of the cleaning efficiency of domestic washing machines with artificially soiled test cloth. In *Energy efficiency in household appliances and lighting* (pp. 95-105). Springer.
Trevisan, A. H., Castro, C. G., Gomes, L., & Mascarenhas, J. (2022). Unlocking the circular ecosystem concept: Evolution, current research, and future directions. *Sustainable Production and Consumption*, *29*, 286-298.
van Langen, S. K., Vassillo, C., Ghisellini, P., Restaino, D., Passaro, R., & Ulgiati, S. (2021). Promoting circular economy transition: A study about perceptions and awareness by different stakeholders groups. *Journal of Cleaner Production*, *316*, 128166.
Vanegas, P., Peeters, J. R., Cattrysse, D., Tecchio, P., Ardente, F., Mathieux, F., Dewulf, W., & Duflou, J. R. (2018). Ease of disassembly of products to support circular economy strategies. *Resources, conservation and recycling*, *135*, 323-334.
Velenturf, A. P., Purnell, P., Tregent, M., Ferguson, J., & Holmes, A. (2018). Co-producing a vision and approach for the transition towards a circular economy: perspectives from government partners. *Sustainability*, *10*(5), 1401.
VHK, V. (2014). Omnibus. *Review Study on Cold Appliances, Washing Machines, Dishwaschers, Washer-Driers, Lighting, Set-top Boxes and Pumps*.
Voulgaridis, K., Lagkas, T., Angelopoulos, C. M., & Nikoletseas, S. E. (2022). IoT and digital circular economy: Principles, applications, and challenges. *Computer Networks*, 109456.
Walden, J., Steinbrecher, A., & Marinkovic, M. (2021). Digital product passports as enabler of the circular economy. *Chemie Ingenieur Technik*, *93*(11), 1717-1727.
Wasserbaur, R., Sakao, T., & Milios, L. (2022). Interactions of governmental policies and business models for a circular economy: A systematic literature review. *Journal of Cleaner Production*, *337*, 130329.

Wieringa, R. J. (2014). *Design science methodology for information systems and software engineering*. Springer.

Wilkinson, M. D., Dumontier, M., Sansone, S.-A., Bonino da Silva Santos, L. O., Prieto, M., Batista, D., McQuilton, P., Kuhn, T., Rocca-Serra, P., & Crosas, M. (2019). Evaluating FAIR maturity through a scalable, automated, community-governed framework. *Scientific data*, *6*(1), 174.

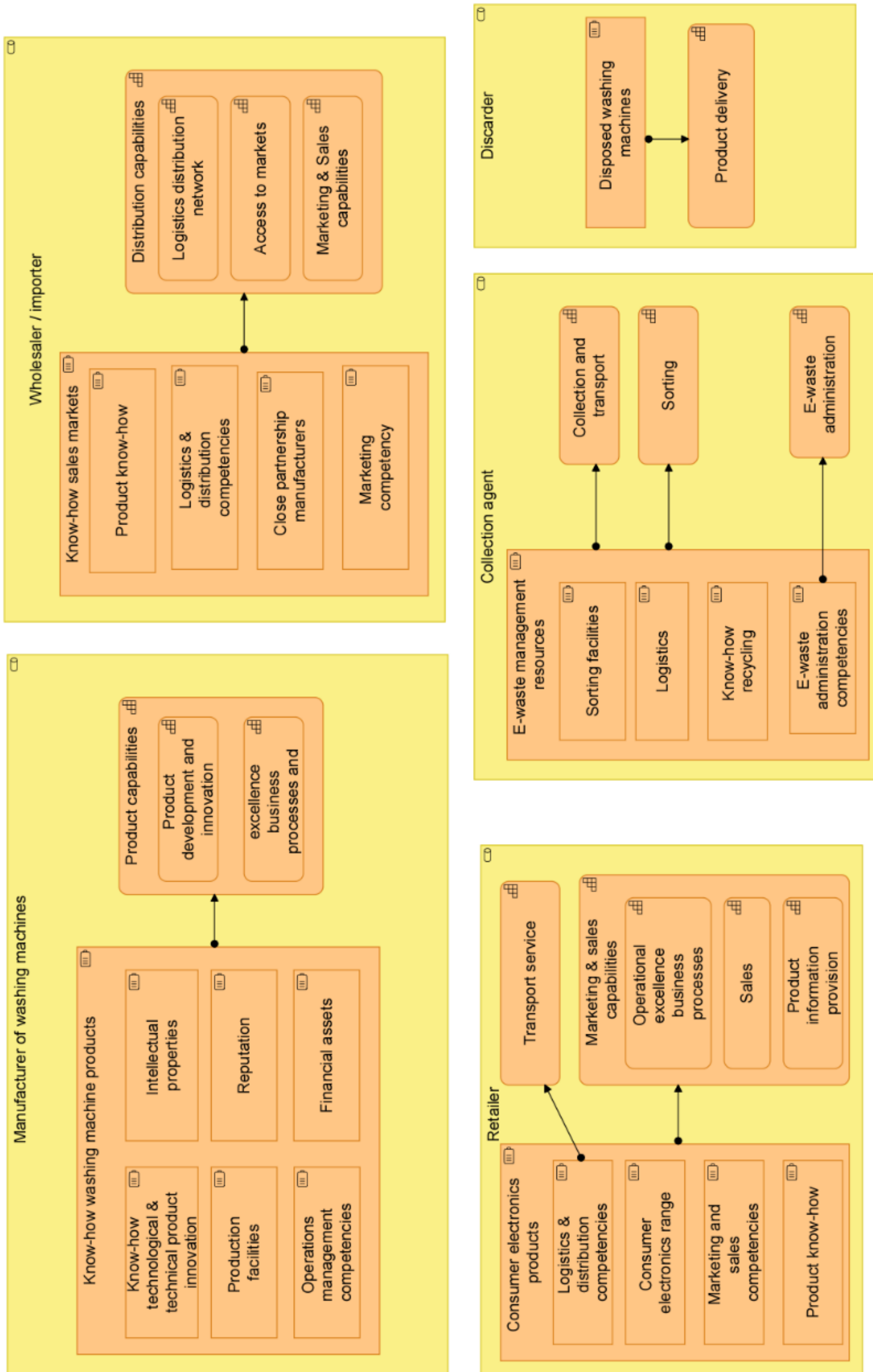
Yin, R. K. (2009). *Case study research: Design and methods* (Vol. 5). sage.

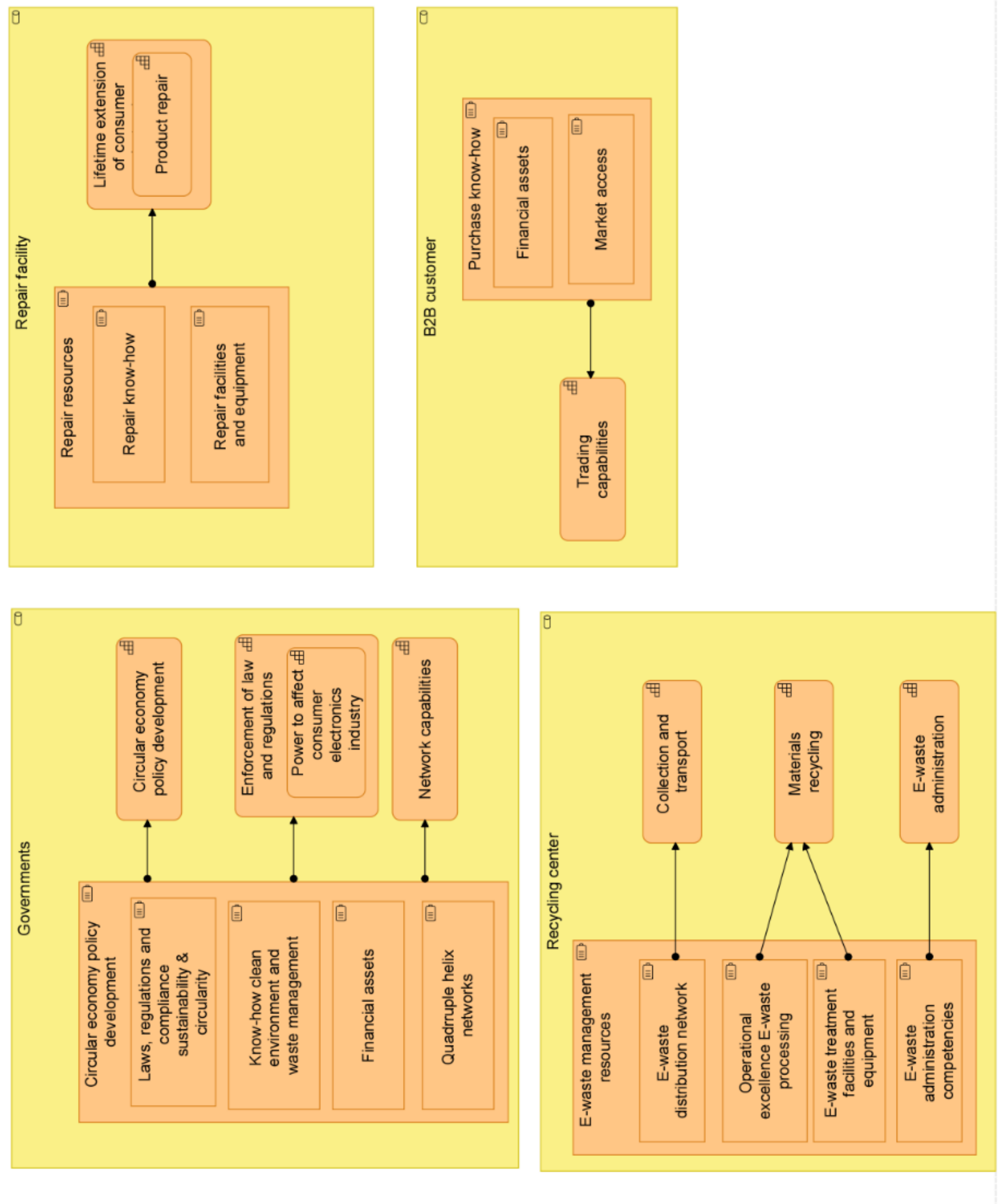
Ylä-Mella, J., Keiski, R. L., & Pongrácz, E. (2022). End-of-Use vs. End-of-Life: When Do Consumer Electronics Become Waste? *Resources*, *11*(2), 18.

Zacho, K. O., Bundgaard, A. M., & Mosgaard, M. A. (2018). Constraints and opportunities for integrating preparation for reuse in the Danish WEEE management system. *Resources, conservation and recycling*, *138*, 13-23.

Appendices

A. Resources and capabilities washing machine ecosystem





Repair facility
Repair resources
Repair know-how
Repair facilities and equipment
Lifetime extension of consumer
Product repair
B2B customer
Trading capabilities
Purchase know-how
Financial assets
Market access
Governments
Circular economy policy development
Laws, regulations and compliance sustainability & circularity
Know-how clean environment and waste management
Financial assets
Quadruple helix networks
Circular economy policy development
Enforcement of law and regulations
Power to affect consumer electronics industry
Network capabilities
Recycling center
E-waste management resources
E-waste distribution network
Operational excellence E-waste processing
E-waste treatment facilities and equipment
E-waste administration competencies
Collection and transport
Materials recycling
E-waste administration

B. Current system solutions overview

Case study Organization 1: Return logistics center 1

System description

A wide variety of returned items from E-commerce retailers are received and registered in a warehouse. Expert graders assess the state of the products at grading stations. An intelligent data-driven system estimates appropriate sales channels for a returned product. Products that require repair and have sufficient residual value are repaired.

System strengths

- Returned products are perceived to maximize the residual value they contain.
- The high-quality return evaluation ensures that almost all returned products get a second life at an acceptable price.
- The delivery, grading, and distribution processes are automated.
- Available product, price, historical, customer, and motivational data of returned products contribute to informed decisions about follow-up process routes and connections to promising sales channels.
- Data-driven decision support system contributes to objectified informed decisions.
- Self-learning system that continuously improves itself.
- Grading experts systematically assess the condition of a product based on established parameters.
- Operational excellence value strategy, high degree of process standardization.
- A digital system instructs employees at every grading process step. Prescriptive standardized choice options are visualized for employees on screens.

System drivers

The number of returned products is increasing significantly. Utilization of remaining economic value of returned products.

Weaknesses

- System viability requires large volumes due to small profit margins.
- System integration with value chain actors requires great effort.
- The delivery of the data packages by the organization's customers is often incorrect. It takes a great deal of effort to receive appropriate data on incoming products.
- The system focuses on a generic, economically driven process approach.
- A specialist process approach that thoroughly assesses lifetime extension aspects of products is not economically feasible due to the enormous product breadth.
- Repair of EEE products is often based on the tacit knowledge of repairers under the influence of various products.
- The organization's high level of technological readiness and its supplying customers are required to enable high service levels.

- Specific repair expertise is required when repairing EEE products.
- Substantiation of process routes that follow from the assessment of EEE products requires detailed insight into value chains and promising sales markets.

Lessons learned

- Continuous process optimization of return logistics and data availability are necessary conditions for carrying out lifetime extension assessments effectively and efficiently.
- Interorganizational system connectivity with collaborating value chain actors.
- For data availability of each returned product, the system offers many possibilities for thorough assessment and objective determination of informed decisions concerning lifetime extension.
- Operational excellence is a distinctive value strategy contributing favorably to the economic feasibility of return logistics and evaluation. Standardization of input, throughput, and output process steps.
- A systematic and straightforward method of product assessment by grading experts based on critical parameters.
- As part of the grading process, a digital application guides employees step by step through standardized tasks.

Relevant system functionalities

- Data management, data integration, product identification, (big) data analytics, product assessment, decision support, business intelligence dashboards.

Case study Organization 2: Return logistics center 2

System description

Provides after-sales services for stores, E-commerce retailers, distributors, and importers of consumer electronics, mainly small household appliances. Provides solutions for handling returned and defective consumer goods, which in most cases are within the warranty period. The services focus on the value retention of returned products.

System strengths

- The residual value of an EEE product is optimally utilized by applying high-quality circular strategies.
- Parts for electronics are harvested from depreciated EEE products, contributing to economic feasibility of product’s repair.
- The focus on small household appliances (as opposed to white goods products) offers logistical and economic advantages. Qualified technical personnel diagnose the returned EEE product and define a process route to recover the product.
- Employees recently reintegrated into the labor market and with little technical background carry out demarcated standardized repair work.

- Interorganizational connectivity with value chain actors’ digital systems contributes to data exchange and availability in the reverse logistics and product recovery process.
- Control for short lead times of EEE products.
- The entire product recovery process is standardized and registered in a digital system.
- Digitized parts inventory system.

System drivers

Exploiting the remaining economic value of EEE products. The organization receives a fixed fee per repaired device.

Weaknesses

- Labor and transportation costs pressure an EEE's reverse logistics and product recovery profits. Extending the lifetime of cheap EEE products is not economically feasible.
- Small profit margins on repair require standardization of the logistics and repair process.
- In addition to supporting digital systems, employee training is required to carry out their repair tasks.
- The parts inventory system underlying product repair is logistically and economically complex. Parts of older products are difficult to obtain and are expensive.
- The system is unsuitable for some EEE product categories, such as white goods and flat screens.
- Social job creation contributes to economic viability and an inclusive personnel policy.
- Large volumes of returned products and multiple clients contribute to the economic viability of lifetime extension of EEE products.

Lessons learned

- Operational excellence and related process standardization in supporting digital systems as a distinctive value strategy that contributes favorably to the economic feasibility of return logistics, return evaluation, and product recovery.
- Interorganizational system connectivity with collaborative value chain actors.
- Harvesting parts from existing EEE products contributes to the economic feasibility of lifetime extension.

Relevant system functionalities

- Product assessment, data management, data integration, prescriptive digital assessment protocols, repairing.

Relevant system functionalities

- Data management, data integration, product identification, (big) data analytics, decision support system, product assessment, business intelligence dashboards.

Case study Organization 3: Mobility aids provider

System description

Mobility aids (e.g., scooters and wheelchairs) enter the return evaluation process after a cycle of use. Based on product, historical use, and repair data, the organization decides to what extent extending the lifetime is possible and what possible product repair work is required.
Reusing parts, reconditioning, remanufacturing, repairing and process, and product optimization with suppliers contribute to extending the lifetime of products.

System strengths

- The process aims to extract the highest economic and ecological value from a returned product.
- Products are rated at the part level rather than the product level.
- Employees at the return evaluation centers have a web application 'value tool' on tablets that supports them with intake, technical inspection, and product repair, and keeps stock of spare parts. The app indicates the optimal choice to get the most value from a part and product. Data-driven decision support leads to objectified informed decisions at the component and product level.
- The system provides employees with data about the product and its history and prescribes which checks must be performed, contributing to informed decisions about extending product lifetime.
- Harvesting parts from products that no longer function.
- Personnel with little technical background can perform actions.
- Reintegrating employees carry out dismantling work.

System drivers

- Circular business strategy to generate no waste by 2030 by extending the lifetime of mobility aids.
- The organization owns the products. Utilizing the highest residual economic and ecological value from returned products is crucial. Circular strategies result in cost savings in purchasing new parts and a lower environmental impact.
- The high initial product and residual economic value, in addition to the high product quality of mobility aids, encourage product reuse over multiple user cycles.

Weaknesses

- Datafication of the entire process during all use cycle phases is necessary.
- Standardization and objectification of return evaluation and possible circular strategy by applying algorithms, methodologies, and calculation tools are complex. Diversity of products, product types, parts and situational factors complicate standardization and decision-making.
- A constant flow of returned products is required.
- Interorganizational collaboration with value chain suppliers is required to realize high-quality circular strategies.
- Product and repair specific knowledge to perform repair tasks are not fully covered in the software application of the organization.

Lessons learned

- Data-driven applications enable employees to make objective informed decisions concerning lifetime extension during an assessment.
- Operational excellence and related process optimization and standardization as a distinctive value strategy contribute to the economic feasibility of return logistics and evaluation and the enables deployment of employees with a minimal technical background.
- Early anticipation of possible reuse of parts to stimulate repair.

Relevant system functionalities

- Data management, data integration, product identification, (big) data analytics, decision support system, product assessment, business intelligence dashboards, repairing.

Case study Organization 4: ICT services developer

System description

Software tool enabling recycling companies to optimize their business processes for EEE products, from product intakes to sales at thrift store checkouts. The system has several applications, such as a logistics planning system, an assessment system, and a cash register system.

System strengths

- After a visual check, collected EEE products that are viable for reuse are assessed for lifetime extension using a structured and data-driven system.
- Generating a unique product identification code enables the tracking and tracing of an EEE product in the value chain.
- Sales prices are defined early in the process.
- The development of a database for collected EEE products facilitates product identification.
- A transparent product sheet is created for each EEE product, which, in addition to product information, contains information about suppliers, location, pricing, test results and repair activities, transportation, product and repair documentation, and product status.

System drivers

- Collected EEE products are assessed by the software tool in a structured and data-driven manner for sale in promising markets in Belgium and the Netherlands.
- Lifetime extension is part of the organization's business strategy as part of the transition to a circular economy.

Weaknesses

- Only a fraction of the supplied EEE products is suitable for reuse.

- Building a database with product and repair information is time-intensive and affected by the variety of brands and product types.
- Interoperability data issues with value chain systems partners.
- Employees find the transition to the digital software application difficult because they are not used to it.

Lessons learned

- Unique product identification contributes to the tracking and traceability of a product.
- Datafied product sheets that contain identification of the product, and the logistical and technical information in different phases of its life cycle enable complete transparency of the return evaluation process.
- Standardized test documents that an employee of a technical workshop works through.
- Developing a database for collected washing machines supports product identification, information provision, and process efficiency.

Relevant system functionalities

- Product registration, product identification, product assessment, data management, data integration, data analytics, decision support system, product recovery.

Case study Organization 5: EEE collection agent

System description

The organization carries out the collection and processing of E-waste. Discarded white good products are collected on a large scale via various return logistics channels and are delivered to the return evaluation center. A lifetime extension assessment is performed based on tacit knowledge and visual characteristics. A repair center is part of the collection service. If necessary, washing machines are refurbished or repaired. Harvesting parts for common high-end brands and washing machine product types occur.

System strengths

- Large volumes of collected and reused washing machines.
- With few resources, a working collection system for white goods has been set up that favors lifetime extension.
- Quick visual checks and technical tests objectify whether lifetime extension is possible.
- Standardization of work ensures that employees with limited cognitive and technical capabilities can perform collection and repair process tasks.

System drivers

- Turnover increase and market growth by extending lifetime of collected white goods.
- Circular innovation through product lifetime extension in addition to recycling activities.

- Lifetime extension of discarded washing machines.
- Job creation for reintegrating employees on the labor market.

Weaknesses

- Manufacturers do not provide licenses to gain digital access to read washing machines.
- The system is mainly suitable for older-generation mechanical washing machines and less for machines with digital technologies.
- No product and usage information.

Lessons learned

- Pragmatic content of system design. Fewer resources enable an efficient system.
- Basic assessment checks provide a realistic estimate of lifetime extension possibility.
- Deployment of reintegrating employees to the labor market performing simple, standardized tasks.

Relevant system functionalities

- Product assessment.

C. Results workshop socio-technical scenarios

Categorie 1: Ontwikkelingen in samenleving / societal development

Waarden en normen t.a.v. hergebruik van EEA verschuiven onder burgers

Meer armoede onder burgers a.g.v. economische krimp

Right to repair beweging is gegroeid, burgers zijn zich bewuster van hun reparatierechten en transparantie en claimen deze rechten

Repair society is toegenomen: burgers besteden meer aandacht aan onderhoud en reparatie van hun eigen EEA, meer repair communities

Burgers hebben toegang tot reparatie- en onderhoudsinformatie

Regionale en lokale reparatie ecosystemen zijn verder geprofessionaliseeerd en verankerd in de samenleving waardoor laagdremelige toegang tot reparatie informatie mogelijk is..

Toenemende bewustwording burgers grondstoffen- en energieschaarste, klimaatverandeirng en transitie naar circulaire economie

Toenemend aantal burgers wil zelfvoorzienend leven en niet belanden in lock-ins. Zij claimen in toenemende mate hun eigen data

Reparatie en onderhoud van EEA is onder burgers breed geaccepteerd.

Toename van conscinious marketing, campagnes en reclame in de media die circulair en duurzaam gebruiks- en koopgedrag aanmoedigt is toegenomen.

Toenemende sense of urgency onder burgers naar een hergebruik-samenleving t.a.v. consumptiegoederen

Burgers hebben steeds meer toegang tot de data die hun EEA genereren, hetgeen gunstig bijdraagt aan hun bewustwording en onderhoud en reparatie stimuleert..

Aantal 'groene' consumenten groeit. Van bezit naar toegang tot: verandering van eigendom naar gebruik en prestatiegebaseerde betalingsmodellen.

Burgers komendoor campagnes, onderwijs, etc.steeds meer in aanraking met circulariteits- en duurzaamheidsthema's en zijn zich bewust van maatschappelijke thema's.

De persoonsgegevens van burgers worden actief beschermd door de GDPR-regelgeving

Consumptiepatronen van burgers transformeren stapsgewijs naar meer circulaire consumptiepatronen.

Burgers zijn zich in toenemende mate bewust geworden van hun rechten t.a.v. het gebruik van de data die zij genereren.

Categorie 2: Marktfactoren en business

Tweedehands markt van consumenten-electronica is steeds volwassener en professioneler geworden, dit heeft geleid tot toenemende marktvraag naar gebruikte EEA.

Toename in product-as-a-service business modellen (e.g. pay per use, pay per performance, leasing) in electronicaketen door retailers en producenten naast bestaande sales oriented business model. Eigenaarschap in handen van retailer of producent.

French Repair Index is inmiddels uitgebreid naar andere Europese landen en Nederland. Consumenten zien op labels wat de reparabiliteit van hun wasmachine is en wat de verwachte durability is

Brede beschikbaarheid aan consumenten en transparantie van informatie over economische, ecologische, sociale, technische factoren en productspecifieke informatie stimuleert 'duurzaam' koopgedrag van tweedehands en nieuwe EEA.

Consumentengedrag is katalysator voor een circulaire economie voor EEA. Meer consumenten stellen zich open voor gebruikte consumptiegoederen.

Ontwikkeling naar repair economy, toenemende professioanlisering van reparatiebedrijven en digitale en fysieke reparatie-ecosystemen

Afschaffing BTW op reparatie leidt tot meer reparatie

Professionalsering naar circulaire ambachtscentra heeft zich doorgezet. Brug tussen inname en verkoop van gebruikte EEA.

Professionalisering van inzamelpunten en retourlogistiek leidt tot meer inname, digitale objectievere assessment van ingezamelde wasmachines en hoogwaardige circulariteitsstrategieën.

Bedrijven besteden meer aandacht aan retourstromen en hergebruik.

A.g.v betere inname en beoordeling is het aantal herbruikbare wasmachines toegenomen

Deeleconomie heeft zich voorzichtig doorgezet voor dure EEA met lage gebruiksfrequentie, toename van consumenten-initiatieven die EEA met elkaar delen.

Kansrijke afzetmarkten voor her te gebruiken wasmachines zijn overwegend regionaal en lokaal van aard.

Retailers hebben naast de verkoop van nieuwe EEA de tweedehands markt consumentenelectronica omarmt.

Toename in vintage platformen waar consumenten aan elkaar gebruikte consumentenelectronica verkopen (C2C)

Garantietermijnen en kwaliteitscertificaten van reparatieorganisaties geven consumenten vertrouwen in de kwaliteit van her te gebruiken EEA.

De kwaliteitspercepties van consumenten naar tweedehands wasmachines zijn positiever geworden onder invloed van professionalisering van tweedehands EEA sector.

Sterke toename van wasmachines door producenten op business markten die een circulair productontwerp hebben to improve product reuse, remanufacturing, recycling and cascading.

Scherper inzicht in en monitoring van tweedehands en reparatie van her te gebruikte consumenten-electronica

Meer digitale en fysieke initiatieven t.a.v. professionale marktplaatsen voor geoogste onderdelen

Burgers hebben de middelen en mogelijkheden om op een gedetailleerd niveau toegang te krijgen tot de gegevens van hun EEA en te beslissen wat er met hun gegevens gebeurt door derden

Smart applicaties op wasmachines genereren infromatie. Deze informatie maakt het mogelijk om real-time klantservices te leveren, zoals dse upgrade van een product of onderhoud.

introductie van take-backsystems met statiegeld.

Fijnmazigere inzameling-, distributie en waste management infrastructuur in (regionale) ecosystemen is verder geprofessionaliseerd, waardoor de verbinding tussen aangeboden gebruikte EEA en kansrijke afzetmarkten beter gelegd is.

Brengers van gebruikte EEA ontvangen een incentive die zorgvuldig brenggedrag beloont.

Toename in product as a service business modellen t.a.v. consumenten-electronica in hogere marktsegmenten heeft zich doorgezet.

Toename in smart maintenance business concepten onder invloed van IoT applicaties.

Toename van hoogwaardige inzameling en verwaarding van gebruikte wasmachines

Datagedreven wasmachines / EEA zorgen ervoor dat businesses meer inzicht krijgen in verbruiksgedrag van consumenten, vormen de opmaat naar servicegerichte smart maintenance business concepten die streven naar langdurige klantrelaties en langdurig gebruik van EEA. (Big) data analytiscs van prestaties EEA en verbruiksgedrag onder invloed van cloud computing dragen bij aan CE systeemoptimalisatie en circulaire prestaties.

Categorie 3: Technologie

Toename van digitale wasmachines (IoT applicaties) die producenten op markt brengen

Sterke toename van circular product design of EEA die repareerbaar, durable, reusable en uipgradable zijn, o.a. door toenemende standaardisatie, modularisatie en ease of disassembly

Informatie over productherstel en reparatie is breed beschikbaar voor reparateurs en burgers.

Toename in open source gemeenschappen en data governance die uitwisseling van data stimuleert.

Toenemende interoperability en kwaliteit van data, uitwisseling van data tussen systemen mogelijk door standaardisatie van data formats en API's.

Increase automation and Intelligence AI toepassingen tijdens de productlevenscyclus in alle procesfasen zorgen voor professionalisering van inname, reparatie van wasmachines

Ontwikkeling naar een digitale circulaire economie, dataficering van circulaire electronicaketen. Toenemend aantal digitale tools die inzameling en reparatie van EEA ondersteunen.

Sterke toename in geproduceerde wasmachines die negatieve ecologische impact minimaliseren

Voorzichtige (Europese) initiatieven om de data van wasmachines in de cloud / blockchain te plaatsen voor hele productlevenscyclus

Internet of Things biedt verschillende mogelijkheden, zoals het genereren van diagnostische gegevens, afstandsbediening en service, meting, betaling en firmware-updates.

3D printing, additive manufacturing vergemakkelijkt beschikbaarheid van onderdelen bij reparatie van EEA.

De toegenomen digital product-as-a-service business modellen stimuleren circular product design.

Verplichte digitale product paspoorten voor consumentenelectronica zijn in opkomst en geven informatie over gehele productlevenscyclus

Toename van hergebruik van onderdelen en materialen in elektronische apparatuur a.g.v. hogere productkwaliteit en circulair productontwerp

Digitalisering van productinformatie tijdens de levenscyclus van het product. Eerste initiatieven van digitale productpaspoorten.

Nieuwe informatietechnologieën (bijv. internet der dingen, 3D-printen, enz.) maken de creatie mogelijk van nieuwe bedrijfsmodellen [14] die het gebruik van producten verbeteren en hergebruik, herfabricage, renovatie en recycling mogelijk maken.

Registratie van wasmachines in de cloud. Door de analytische machinetechnische gegevens in de cloud te genereren en te delen, kunnen gebruikers of direct machines bij een storing een serviceverzoek in de cloud plaatsen. De servicekwaliteit van reparateurs wordt dan ook zichtbaar.

Slimme en verbonden wasmachines genereren grote hoeveelheden gegevens. Deze gegevens en big data analytics geven inzicht in de status van de wasmachines, voorspellend onderhoud, gewenste reparaties, en hoe klanten de wasmachines gebruiken.

Door inzet van digitalisering zijn circulaire ketenprestaties in meerdere ketenschakels transparanti

Categorie 4: Rol van overheden

Onder invloed van geopolitieke spanningen streeft overheid naar minder grondstoffenafhankelijkheden en kortere ketens; Europese en nationale transitieopgaven versterken elkaar..

Productbeleid Eco-design EU stelt eisen aan ontwerp, levensduur, reparatie en recycling van consumentenelectronica. Focus op langcyclisch gebruik.

Overheden zijn sturender en eisender onder invloed van aangescherpt circulaire beleid, doelstellingen en de monitoring daar van.

Nationaal Plan Circulaire Economie concretiseert doelen om grondstoffenreductie te realiseren

Regio's en gemeenten spelen grote rol om circulaire economie beleid t.a.v. hergebruik en levensduurverlenging van EEA te effectueren.

Uigebreide producenten-verantwoordelijkheid is verbreed en geeft impuls aan hoogwaardige inname en verwaarding van afgedankte EEA

In Nationaal Programma Circulaire Economie actieve sturing op circulaire beleidsdoelen voor meerdere groepen consumptiegoederen vanuit perspectief meervoudige waaardecreatie.

Elektrische apparaten zijn als productgroep geprioriteerd vanwege hun negatieve ecologische impact expliciet geadresseerd in EU Green Deal en Nationale Programma Circulaire Economie. Actieve right to repair policies voor EEA.

Nationaal Programma Circulaire Economie focussen zich naast hoogwaardige recyclingsdoelen op circulaire doelen die hoogwaardige inzameling, hergebruik, levensduurverlenging en recycling van EEA nastreven

Wettelijke richtlijnen verplichten repair en durability index op elektronische apparatuur. Sturing op toegang tot informatie door burgers.

Sturing op burgerparticipatie initiatieven waardoor burgers actieve participanten worden bij de ontdoening en inzameling van huin gebruikte EEA.

EU en Nederland hebben in EU Data Strategy en Nederlandse Digitaliseringsstrategie sterk ingezet op digitalisering. Digitalisering en een beter datagebruiks als versnellers en enablers van circulaire innovatie om maatschappelijke en economische kansen van transitie naar een (digitale) circulaire en data economie te te benutten..

EU Data Governance ACT biedt eerlijke regels voor toegang tot, deling van en (her)gebruik van data.door verschillende stakeholders. .

Naast een faciliterende en stimulerende rol om de achtergebleven transitie naar een circulaire te versnellen, hanteren overheden meer normerende en beprijzende sturingsinstrumentaria.

EU heeft met haar Green Deal en Circular Action Plan ingezet op hergebruik, levensduurverlenging en repareerbaarheid van consumenten-electronica

Overheden investeren veel (o.a. door subsidies) in circulaire initiatieven t.a.v. levensduurverlenging en hergebruik.

Categorie 5: Macro factoren

Toenemende geopolitieke spanningen in de wereld maken kwetsbaarheid global supply chains consumenentenelectronica zichtbaar

De Right to Repair beweging is groter geworden en zet producenten onder druk om levensduurverlenging van EEA te vergemakkelijken.

Energietransitie accelereert onder invloed van geopolitieke spanningen en klimaatverandering.

De grondstof en energieprijzen nemen sterk toe en zijn volatiel vanwege schaarste en geopolitieke ontwikkelingen.

De kosten van levensonderhoud zijn het afgelopen decennium structureel toegenomen. Veel consumenten en bedrijven hebben steeds minder grip op hun financiële situatie.

Toenemende leveringsonderzekerheden van grondstoffen voor productie en herstel van consumentenelectronica

De gevolgen van kimaatverandering worden steeds zichtbaarder, bijv. door droogte, overstromingen en hitte.

Toenemende voelbare grondstoffen- en onderdelenschaarste bij productie en herstel van consumentenelectronica

D. Operationalization of lifetime extension assessment criteria

Assessment category	Assessment criteria	Relevance	Primary data indicators	Required information sources	Secondary data indicator	Possible information sources
1. Product characteristics	Product quality	The product quality of the materials, parts, connectors and the product as a whole affects the washing machine's lifetime.	Direct data on product quality of materials and components. Data of suppliers and manufacturers in electronic materials passports.	Not available and accessible for third parties.	Brand. The product quality of washing machines varies significantly by brand.	Partially. European Product Registry for Energy Labelling has registered EEE products since January 1, 2019. Before this date, data is not available. Product information such as washing machine brand can be obtained based on the unique product identity. Visual inspection.
					Product/model type. Market segmentation occurs within brands by applying price differentiation between product types.	Partially. European Product Registry for Energy Labelling has registered EEE products since January 1, 2019. Before this date, data is not available. Product information such as washing machine product / model type can be obtained based on the unique product identity. Historical databases of manufacturers and retailers. Not available and accessible for third parties.
					Initial catalogue price. The initial catalogue price is often a derivative of the product quality of a washing machine.	Product information such as initial catalogue price can be obtained based on the unique product identity. Historical databases of retailers. Not available and accessible for third parties.
					Physical state of washing machine. E.g., rust, corrosion, dents.	Visual inspection of physical state.
	Physical product properties	Type washing machine. Compared to top loaders, the market demand for front loaders is high.	Product information such as washing machine type can be obtained based on the unique product identity (e.g., model type, serial number).	Digital manuals. Website of manufacturer. Self-repair websites.	Visual observation.	Visual inspection of washing machine type.
		Product features on a washing machine, such as load weight, method of operation, and washing programs, contribute to the extent to which a product is attractive to potential customers.	Product information, such as product features, can be obtained based on the unique product identity.	Partially. European Product Registry for Energy Labelling has registered EEE products since January 1, 2019. Before this date, data is not available. Digital manuals. Website of manufacturer. Self-repair websites.	Visible product features on washing machine. E.g., washing machine programs and load weight.	Visual inspection.
	Product performance specifications.	Technical performance specifications, such as spin speed, washing result, energy efficiency, and water	Product performance specifications can be obtained based on the	European Product Registry for Energy Labelling has registered EEE products since	Energy label	Digital manuals. Website of manufacturer. Self-repair websites. Printed / digital energy labels.

		consumption, contribute to the attractiveness of a product to potential customers.	unique product identity in product manuals.	January 1, 2019. Before this date, data is not available. Digital manuals. Website of manufacturer. Self-repair websites.		
2. Washing machine health	Product status	Functioning signals indicate whether the device is viable.	Voltage on device.	Some current digital washing machines provide product status information. Not possible for older mechanic washing machines.	Voltage on device.	Voltage meter test.
					Performing washing machine program.	Washing program tests reveal technical functioning of washing machine (e.g., voltage, leakages, electronics).
	Physical condition of device	The physical condition of a washing machine is determined by its external and internal visual appearance.	Rust. Dents, scratches. Corrosion. Hygiene.	Visual inspection.	-	-
	Completeness of washing machine	The completeness of a washing machine affects if additional spare parts are required allowing product repair.	Presence of internal and external parts.	Some current digital washing machines provide functioning and related presence of spare parts. Not possible for older mechanic washing machines.	Visual observation of external and visible internal spare parts.	Visual inspection.
	Failure diagnostics	Based on the failure diagnosis, current en previous failure modes are identified. The diagnosis allows the definition of possible recovery activities.	Fault memory.	Some current digital washing machines offer fault diagnosis and fault memory. Older mechanical washing machines offer access to the fault memory with key combinations.	Technical tests to indicate failure modes.	Multiple tests, such as: Manual bearing test. Manual shock absorber test. Run washing machine programs. Electronics tests.
	Delivered performance	The performance a washing machine delivers after a period of use.	Water and energy efficiency: - energy efficiency class(es) - energy consumption for hundred cycles - water consumption for one cycle - duration for one cycle - noise emissions	European Product Registry for Energy Labelling register EEE products since January 1 2019. Before this date data is not available.	Energy label (water consumption and energy efficiency).	Digital manuals. Website of manufacturer. Self-repair websites. Printed energy labels.
	Repair history	Insight into previous repair activities regarding recovered failure modes provide insight into the condition of a washing machine.	Performed repair activities.	Records of repair service providers. Some current digital washing machines provide repair history data. Not possible for older mechanic washing machines.	Repair traces (e.g., missing parts, damages, usage of different connectors).	Visual inspection.
	Maintenance history	The extent to which previous users of washing machines carried out regular maintenance activities to keep	Performed maintenance activities.	Some current digital washing machines provide information about maintenance history.	Physical state of washing machine. E.g., rust, corrosion, dents.	Visual inspection.

		the washing machine in good working order.		Not possible for older mechanic washing machines.		
	Usage intensity	The frequency of use and frequently selected washing programs in the past.	Number of cycles so far.	Some current digital washing machines provide information about number of washing machine cycles so far. Not possible for older, mechanic washing machines.	Physical state of washing machine. E.g., rust, corrosion, dents.	Visual inspection.
	Treatment behaviors	How a previous user physically treated a washing machine affects its residual life.	User marks, external and internal damage of washing machine.	Visual inspection.	-	-
	Availability of product and repair support information	The extent to which product and repair information is available and accessible to repair service providers influences the repairability of a washing machine.	Availability of product and repair information.	Digital manuals. Websites of manufacturers. Self-repair websites.	-	-
	Spare parts	The extent to which spare parts are still available after several years impacts the repairability of washing machines.	Availability of spare parts.	E-commerce spare parts providers selling new spare parts.	-	-
	Economic feasibility of repair	Possible repair costs affect the economic feasibility of lifetime extension.	Expected repair costs based on a diagnosis. Ratio between repair cost and an initial index price of a washing machine.	Not available. Depends on repair configuration. Expected repair costs are specifically determined by labor and spare parts costs.	-	-
	Residual lifetime	The number of performed wash cycles of a washing machine and its age affect its residual lifetime.	Number of cycles so far. Year of construction.	Not available. Not possible for older mechanic washing machines. Current digital washing machines provide information about the number of machine cycles.	Physical state of washing machine. E.g., rust, corrosion, dents.	Visual inspection.
3. Value chain actors	Value chain actors' professionalism	Value chain actors involved in a device during the product life cycle (e.g., manufacturers, retailers, repairers, and resellers) provide insight into responsible actors related to a washing machine. E.g., compliance with regulations.	Log data. Actor information.	Not available. Future digital product passports might encompass this information. Databases of manufacturers and repair services provide insight into the product life cycle of washing machines.	-	-
4. Environmental aspects	Environmental performance	Energy and water consumption determine the	Water and energy efficiency: - energy efficiency class(es)	European Product Registry for Energy Labelling has registered	Energy label (water consumption and energy efficiency).	Digital manuals. Websites of manufacturers. Self-repair websites.

		ecological impact regarding lifetime extension.	- energy consumption for hundred cycles - water consumption for one cycle - duration for one cycle - noise emissions	EEE products since January 1, 2019. Before this date, data is not available.		Printed energy labels.
	Environmental impact	Life cycle analysis provides insight into the extent to which lifetime extension is acceptable from a sustainable and circular perspective.	Life cycle impact categories and indicators (e.g., CO2 footprint, land use, toxicity).	Available LCA databases for inventory data, calculation methods, assessment methods.	Multiple indicators, e.g.: Kilograms prevented waste. Saved CO2 emissions (in kg) for the EEE and EEE parts to be used because lifetime extension is possible. Saved E-Waste due to reuse of materials and parts (in kg and numbers). Total saving of raw materials and materials (e.g., metals, gold, plastic) in kg during extraction because it is possible to extend the lifetime of EEE. Total saving of energy consumption (in Watt) during production of new EEE because lifetime extension of EEE is possible. Total savings of water consumption (in liters) during production of new EEE because EEE lifetime extension is possible.	Not available. Standard rules of thumb applicable to any average washing machine.
	Circular product design strategies	The leading design strategy of a washing machine influences the durability and repairability of washing machines.	Applied design strategy principles.	Not available. Manufacturers do not share this data. French repair index methodology provides quantitative information about repairability scores for EEE products. Not available in the Netherlands.	Brands. Compared to other brands, the repairability of German-brand washing machines is higher.	Partially. European Product Registry for Energy Labelling has registered EEE products since January 1, 2019. Before this date, data is not available. Product information such as washing machine brand can be obtained based on the unique product identity. Visual inspection.
	Product repairability	The repairability score determines the extent to which a washing machine is repairable.	Repairability score	French repair index methodology provides quantitive information about the repairability score for EEE products. Not available in the Netherlands.	Brands. Compared to other brands, the repairability of German-brand washing machines is higher.	Partially. European Product Registry for Energy Labelling has registered EEE products since January 1, 2019. Before this date, data is not available. Product information such as washing machine brand can be obtained based on the unique product identity. Visual inspection.
	Social impact	The extent to which lifetime extension contributes to inclusive personnel policies.	Number of reintegrating employees on the labor market.	Not available. Depends on configurational settings.	Number of reintegrating employees on the labor market.	Standard rules of thumb applicable to washing machines.
5. Market demand	Expected market demand	Quantified verwachte marktvraag naar wasmachines	Numbers of sold washing machines differentiated by	Statistic databases explaining consumption	Qualitative estimations of expected market demands by sellers.	Retailers selling second-hand washing machines estimate expected demand for

		gedifferentieerd naar merk en producttype.	brand, product type, and price.	trends and developments. Not available for past transactions.		washing machines differentiated by brand and product type.
	Expected pricing	The expected price at which a reusable washing machine can potentially be sold affects the economic attractiveness of lifetime extension.	Pricing trends.	Websites (e.g., Tweakers.net) provide insights into historical pricing trends.	Experience of sellers.	Retailers selling second-hand washing machines estimate expected selling price for washing machines differentiated by brand and product type.

E. Use cases

Use case 1: Wasmachine producent

De rol van wasmachine producenten gaat de komende jaren stapsgewijs veranderen. Schaarste aan grondstoffen en risico's t.a.v. leveringszekerheid van materialen en onderdelen zorgen ervoor dat producten, onderdelen en materialen van wasmachines langer in circulatie gehouden moeten worden. Producenten reageren hierop door hun verdienmodel niet enkel en alleen uit het produceren van wasmachines te halen, maar ook uit het verlengen van de levensduur van apparaten door levensduurverlengende services aan te bieden.

Onder invloed van nationale en Europese wet- en regelgeving worden wasmachines die lang meegaan en levensduurverlenging & hergebruik van deze wasmachines steeds belangrijker. Krachten als de Right-to-repair beweging en Europese Ecodesign richtlijnen stimuleren producenten om in hun wasmachine productontwerp levensduurverlenging & hergebruik te incorporeren, zoals een gemakkelijke reparatie of upgrade van een wasmachine. Wasmachines worden gebouwd voor hele productlevenscyclus, van productontwerp tot inname. Servicegerichte business modellen en een toenemende vraag van consumenten naar kwalitatief hoogwaardige en energiezuinige wasmachines geven producenten in toenemende mate incentives om wasmachines te produceren en te onderhouden die aan deze kenmerken voldoen. In dit kader wordt de hele keten steeds belangrijker voor producenten: van verantwoord produceren tot en met een verantwoorde inname aan de End-of-Life van een afgedankte wasmachine.

Producenten van wasmachine worden in toenemende mate verplicht om over hun product transparante informatie te verschaffen. Deze informatie heeft o.a. betrekking op de grondstoffen die in een elektronische product zitten, op welke locatie het product gemaakt is, in welke mate het product duurzaam geproduceerd is, welke sociale maatstaven zijn gehanteerd tijdens het productieproces en wat de producteigenschappen zijn (zowel fysieke eigenschappen als de prestaties van een prestaties).

Een producent zoekt onder invloed van toenemende wet- en regelgeving en een toenemende vraag vanuit de markt naar mogelijkheden om sustainabity & circularity doelen te realiseren door de E-waste value chain effectief te managen. Een producent wil daarom graag inzicht krijgen in de prestaties van de wasmachines tijdens de gehele productlevenscyclus en zorgen dat het apparaat aan de End-of-Life weer terugkomt bij de producent. De toenemende focus op circulariteit door wasmachine producenten leidt tot toenemende ketensamenwerking met value chain actors en de informatiebehoeften op dit vlak. Bijv. t.a.v. retourzendingen en gebruiks- & onderhoudshistorie. Producenten gaan actiever aan de slag met retourstromen en het terugwinnen van economische waardevolle onderdelen die hergebruikt kunnen worden. Producenten gaan op kleine schaal hoogwaardig hergebruik van producten stimuleren door refurbishment en remanufacturing.

Om de veranderende rol van producenten optimaal te kunnen uitvoeren, is informatie over bovenstaande onderwerpen in het digitale product paspoort nodig. Producenten willen hun wasmachine tijdens de gehele productlevenscyclus kunnen volgen, inzicht hebben in de technische prestaties van het apparaat en zien welke value chain actors bepaalde activiteiten hebben uitgevoerd om de levensduur te verlengen. Consumenten en reparateurs vragen producenten om informatie om inzicht te krijgen in de circulaire en economische prestaties van hun wasmachine, bijv. de mate van repareerbaarheid, energiezuinigheid, milieubelasting en total cost of ownership. Wetgevende organen willen inzicht krijgen of vigerende wet- en regelgeving door producenten wordt nageleefd.

Use case 2: Retailer

Doel: Als verkopende partij aan klanten informatie verstrekken die hen helpt om inzicht te krijgen in de productkenmerken, technische staat, prestaties, eventuele levensduurverlengende reparaties, de verwachte levensduur en repareerbaarheid van een (nieuwe of her te gebruiken) wasmachine geven om klanten te ondersteunen een geobjectiveerde koopbeslissing te kunnen nemen.

Deze use case heeft betrekking op retailers die nieuwe wasmachines of gebruikte wasmachines verkopen waarvan levensduurverlenging mogelijk is. Retailers willen klanten informatie aanreiken die hen ondersteunt om een weloverwogen koopbeslissing te kunnen nemen. De informatie in het digitale product paspoort helpt hierbij. In het paspoort vindt een retailer de algemene en technische productinformatie over de wasmachine. Om eventuele onzekerheden bij klanten weg te kunnen nemen is in het paspoort informatie over de technische staat / kwaliteit van de wasmachine en de te verwachten resterende levensduur opgenomen. De informatie in het paspoort geeft de retailer ook inzicht in welke eventueel onderhouds- en reparatiewerkzaamheden door welke reparateurs sinds de laatste gebruiksfase zijn uitgevoerd, zoals het vervangen van onderdelen of de upgrade van een wasmachine. Verondersteld wordt dat een retailer klanten stimuleert om ecologische overwegingen in hun koopbeslissing mee te nemen. Om de klant hierin te ondersteunen geeft het digitaal product paspoort inzicht in de duurzaamheids en circulaire prestaties van de wasmachine, zoals water- en stroomverbruik, materialenverbruik en de productontwerpprincipes. Ook bevat het paspoort informatie over de sociale condities waaronder de wasmachine is geproduceerd en gerepareerd. De transactiegegevens van een verkochte wasmachine worden in het paspoort anoniem vastgelegd.

Use case 3: Collector

Doel inzamelaar: de informatie uit het digitale product paspoort moet inzamelaars helpen om de hergebruikopties van een wasmachine objectief te kunnen bepalen.

In de toekomst gaan we uit van een situatie waarbij inzamelaars van afgedankte wasmachines en andere consumentenelectronica een belangrijke rol spelen bij het datagedreven evalueren van een afgedankte wasmachine. Inzamelaars hebben in de nabije toekomst als return evaluation centers een strategisch belangrijke rol om afgedankte wasmachines objectief te beoordelen aan de hand van vastgestelde beoordelingscriteria. Hun huidige rol als inzamelaar is hierbij veranderd naar die van assessor.

Tijdens de lifetime extension assessment is het voor inzamelaars belangrijk om met behulp van de informatie in het digitale product paspoort objectief te kunnen bepalen wat een passende hergebruikoptie voor een afgedankte, ingezamelde wasmachine kan zijn. Bijvoorbeeld (direct) hergebruik, reparatie of recycling van materialen. Als een hergebruikoptie geobjectiveerd is vastgesteld, wordt automatisch de procesroute van het vervolgtraject bepaald. De grading van een afgedankte wasmachine helpt om een eerst schifting te maken in de processtroom aan afgedankte wasmachines die bij een inzamelaar binnenkomt.

De informatie in het digitale product paspoort helpt inzamelaars om een geobjectiveerde beoordeling te maken van de wasmachine om een passende circulaire strategie te kunnen bepalen, zoals reuse of reparatie. Productinformatie, technische informatie, historische gebruiksinformatie, informatie m.b.t. onderhoudshistorie, informatie over de verwachte ecologische impact bij levensduurverlenging en informatie over de mogelijke sociale impact zijn onder andere nodig om afgedankte wasmachine objectief te kunnen graden.

Use case 4: Repairer
Doel reparateur: de informatie in het digitale product paspoort moet herstellers en reparateurs ondersteunen om herstel- en levensduurverlengende werkzaamheden aan een (afgedankte) wasmachine (die gerepareerd kan worden) uit te voeren.

Deze use case heeft betrekking op herstel- and reparatiefaciliteiten waar reparateurs gericht zijn op het diagnosticeren, herstellen (onderhoud, revisie, reparatie) van afgedankte wasmachine met als doel hun levensduur te verlengen. Verondersteld wordt dat de reparateur streeft naar levensduurverlenging, teneinde de duurzaamheids- en circulariteitsprestaties van de te herstellen wasmachine te maximaliseren.

De informatie in het digitaal product paspoort ondersteunt reparateurs om de herstel- en reparatiewerkzaamheden uit te kunnen voeren. In de huidige situatie is de productinformatie over een specifieke wasmachine veelal lastig vindbaar. Historische gegevens met betrekking tot eventuele storingen, gebruikshistorie en onderhoudshistorie ontbreken veelal. In deze use case wordt verondersteld dat deze informatie beschikbaar is in het digitale product paspoort. Deze historische informatie ondersteunen reparateurs in het specifieker diagnosticeren van de wasmachine.

Daarnaast wordt de reparateur ondersteunt in zijn werkzaamheden door informatie m.b.t. foutdiagnoses, informatie m.b.t. de repareerbaarheid (mate van repareerbaarheid en benodigd specifiek gereedschap, informatie m.b.t. repair support (bijv. door een producent of service center), de identificatie van benodigde onderdelen, reparatie instructies, reset-instructies, veiligheidseisen, relevante wet- en regelgeving die in acht dienen te worden genomen. In het digitale product paspoort worden ook relevante testresultaten tijdens de diagnose van de wasmachine en de eindtest opgeslagen. Ook legt de reparateur in het paspoort vast welke herstelwerkzaamheden aan de wasmachine zijn

F. Feedback from experts on digital product passport version 1

Feedback	Consequences for system design of digital product passport version 2
1. Distinguish data recorded in the passport and data that are part of the assessment process, such as laws and regulations and the economic feasibility of a possible lifetime extension.	Investigate the calculation of technical, economic, and ecological feasibility of lifetime extension in the assessment process. Register data on repairability and ecological impact in passport.
2. The division into information categories and data properties in the digital product passport is arbitrary. E.g., the repairability of a washing machine can be a product property but can also be related to the product design.	In the next version, critically test the structure and layout of the digital product passport and link it to use cases.
3. Substantiate the layout and structure of the passport. Investigate the valuable information sources to obtain the digital product passport data. E.g., Global Trade Item Number (GTIN) and EU Energy's labeling framework regulations (EPREL).	Formulate recommendations for promising sources of information to fill passports.
4. Check which data they need for each use case and related value chain actor. Provide insight into which information categories and data properties meet their information needs.	Align the information needs of value chain actors in the use cases with the information in the digital product passport.
5. Explicitly state which information value chain actors add and which information they extract from the passport to make informed decisions.	Address in a process diagram which information value chain actors store and retrieve.
6. Time-dependent data, e.g., costs of spare parts, are highly variable and are not part of the passport, but are invested in the process.	Address process information in the passport in a process diagram.
7. Investigate to what extent aggregated data are part of the digital product passport. E.g., energy costs per year or total cost of ownership.	Aggregated data is not part of the digital product passport. The underlying information that leads to the aggregated data does form part of the passport.
8. The data in the passport have different relevance for the different value chain actors. Not all data specifications are of interest for actors and require a more abstract level of aggregation, e.g., a general score for the repairability or energy efficiency of a washing machine.	No consequences. Relates to use cases.
9. Set restrictions on which data are displayed per value chain actor type. Differentiate the level of detail, access rights, editing rights, rights to add information, and data confidentiality.	Define data restrictions for each data property of the digital product passport. This feedback is outside the study's scope.
10. Record in a digital product passport whether a value chain meets the required legal conditions, such as the WEEELABEX certification.	Define data properties in the passport clarifying whether an actor meets legal requirements.
11. The digital product passport's focus is on the machine's product level. Service lifetime extension also requires information at the component and material levels. In the future, materials will form part of a Materials Passport. Invest this information in the passport.	Include data properties related to part numbers in the passport. Link the digital product passport with a possible materials passport.
12. The elaboration in levels of the digital product passport is not consistent.	The structure of the information categories and data properties is pivotal in the passport. Differentiation by levels is irrelevant.
13. The outcomes of the lifetime extension assessment and possible product repair work of disposed washing machines can be documented in the digital product passport.	No action. Such assessment results can be registered in the value chain actors' information category.
14. Investigate which information category in the digital product passport contains information about the repairability of a washing machine.	The repairability of a washing machine is part of the sub-information category Circular Design-Related Properties.
15. For this study, it is not necessary to operationalize the information category Sustainability and Circularity in specific data properties. The current level of aggregation is sufficient. Life cycle analysis requires many data and entails much complexity. For this study, data on energy and water consumption take priority.	Outline the information category Sustainability and Circularity. Define concrete data properties for energy and water consumption (see information category 1 washing machine product).

G. Feedback on use cases and digital product passport concept

Feedback respondent use case ‘Manufacturer’

Evaluation aspects: use cases	Feedback from respondent	
Role in use case	- Use case is in line with the changing role of producers. - Demand for information is increasing under the influence of the transition to the circular economy and E-commerce retail and requires registration from producers. - Hardware and software applications in washing machines provide insight into the life cycle of a product. - Producers must have insight into logistics and production specifications in their systems. - Spare parts information is relevant. - Life cycle assessment is becoming increasingly important to provide insight into the ecological impact of the product life cycle. - Service-oriented business models stimulate lifetime extension and a product life cycle approach. - Value chain actors must develop systems to support transition to service-oriented business models. - Right to repair requires components to be in stock for a long time. Address relevance of inventory system in use case. - Emphasize relevance of return flows in use case. - Relevance of sustainability and circularity aspects is becoming increasingly important for producers and consumers.	
Information needs	- Broad set of information in the use case meets the information needs of the manufacturer. - The question is who gets access to information (technical and security considerations). - Include future contracts with customers in the DPP, e.g., under the influence of a repurchase obligation. - Washing machines equipped with digital technologies enable data generation and monitoring. Emphasize in use case what possibilities this data has. - Expanding information provision to collectors and third parties for return flows in the future.	
Evaluation: digital product passports	- Information categories in DPP cover information needs of producers. - Under the influence of the internet-of-things application, the DPP receives real-time information, which gives it a dynamic character.	
Evaluation: information category 1 Washing Machine Product	- Include data about software version and upgrades in DPP. - Include hardware specifications. - Add service manuals containing maintenance and repair information. - Record the unique coding of parts in the DPP. - Record in the DPP which tools are needed for repairs.	Priority: Must have (primary priority, essential for lifetime extension of washing machines)
Evaluation: information category 2 Value Chain Actors	- Relevant for manufacturers due to transition to service-oriented business models. This requires transparency and traceability. - Determine the location of chain partners via GPS coordinators. - Create an access log in DPP. - Record customer approval for IoT products in DPP.	Priority: Could have (desirable but not essential)
Evaluation: information category 3 Diagnostics, Maintenance and Performance	- This information category requires that the supporting data in information category 1 in the DPP is in order. - Future monitoring of washing machines requires differentiation by washing machine component level. - The diagnosis of washing machines is becoming more specific under the influence of digital technologies and predictive maintenance is being stimulated. The role of maintenance is becoming increasingly relevant in extending the lifetime.	Priority: Must have (primary priority, essential for lifetime extension of washing machines)
Evaluation: information category 4 Sustainability and Circularity	- The detailed information in this category requires a lot of data and assumptions. Phase the information provision over time. Producers often do not have the necessary information. - It must be clear to producers which activities (such as lifetime extension and maintenance) can contribute to footprint reduction. - Certification of value chain actors is becoming increasingly important for sustainability issues. - Accountability of social impact is becoming increasingly important.	Priority: Could have (desirable but not essential)

Feedback respondent use case commercial retailer

Evaluation aspects: use cases	Feedback from respondent	
Role in use case	The role of retailers will change in the coming years. Environmental issues and water and electricity consumption have become more critical for consumers in the short term. Retailers notice that the environmental awareness of our customers is increasing. In the use case, I see a great deal of information that retailers can use to advise customers when purchasing washing machines. We only sell new washing machines in our store. Although social issues are currently not part of the sales process, I can imagine that this will become increasingly important in the future because the passport provides insight into the entire life cycle of a washing machine.	
Information needs	The use case meets the retailers' information needs supporting the sales conversation with our customers. Ecological information is becoming increasingly important when advising customers on consumer electronics. Retailers want to provide customers with information about washing costs in terms of electricity and water and financial consequences for customers and the environment. The use case also discusses the social impact. At the moment, it is difficult to control under what conditions a washing machine has been produced. Social aspects are not yet a selling point, but I can imagine this will change in the coming years, especially if this is made transparent through information provision. Ultimately, I see for our customers that financial information about a washing machine is the most important issue when advising on the suitability of a washing machine. Financial information should be included in the passport. Including the listed price in the passport is a good example of this. As an electronics retailer, I notice that customers' sales decisions are mainly economically driven. Purchase price now determines, in many cases, which brand and type of washing machine a customer purchases. I expect this will shift for some of our customers in the coming years, with information about the environment and consumption becoming more critical. I see this information in the information categories in the digital product passport.	
Evaluation: digital product passports	The different information categories of the digital product passport make sense to me as a retailer. The information categories contain much data about washing machines. As a retailer, we retrieve data in manufacturers' databases of washing machines that we work with.	
Evaluation: information category 1 Washing Machine Product	Agree. In this information category, valuable product information is stored which we usually obtain from the service support systems of washing machine manufacturers.	Priority: Must have (primary priority, essential for lifetime extension of washing machines)
Evaluation: information category 2 Value Chain Actors	Agree. The data in this information category ensures that we, as retailers, have knowledge of the history of a washing machine. Make sure that recording data in the DPP takes enough time. The time effort must be in proportion to the list price of a washing machine.	Priority: Won't have (not essential, can be included in future when conditions are more favorable).
Evaluation: information category 3 Diagnostics, Maintenance and Performance	The data in this information category is sufficient. For new appliances, this information category is less relevant because the physical condition of the washing machine is still new. As a retailer, we do not sell second-hand washing machines. Retailers selling second-hand washing machines will benefit from this information category because it contributes to their reliability for customers.	Priority: Should have (primary priority, essential for lifetime extension of washing machines)
Evaluation: information category 4 Sustainability and Circularity	This category of information is helpful for retailers. Sustainability information enables retailers to advise customers properly as to which washing machine brand has the smallest footprint. The differences between the different washing machine brands are increasing because the ecological information provides a clear insight into the environmental impact. This information will affect the purchasing decision of customers. For example, a German washing machine has a lower environmental impact than a Samsung washing machine from Asia.	Priority: Could have (desirable but not essential)

Feedback respondent use case thrift store retailer

Evaluation aspects: use cases	Feedback from respondent	
Role in use case	In this use case, the connection with the use case “repair” is important for us as a retailer selling second-hand washing machines. Make sure you provide relevant information to customers in an understandable way, e.g., in pictographs, so that they can make an informed purchasing decision.	
Information needs	Customers are increasingly asking questions about energy consumption, history, and expected lifetime of reusable washing machines. To a certain extent, we can provide this information, but much information is insufficiently recorded, so sharing information with customers is impossible. The information needs explained in the use case, respond to the information that retailers would like to communicate to our customers. We also observe that customers are increasingly asking questions about the ecological impact of reusable washing machines. The information provided enables them to glean information on the degree of sustainability and to adjust their purchasing decision accordingly. The most important thing is that the information described in the use case and the digital product passport gives customers confidence in the technical quality of a reusable device and how long it can last. The broad set of information needs in the use case is in line with our customers, who are becoming increasingly demanding when making an informed purchasing decision. The information needs mentioned in the use case, help us to improve and broaden our role as a retailer. This could be by informing the customer how long the washing machine can still last, what the expected running costs are, how environmentally friendly a washing machine is, and how the appliance and its parts have been produced (e.g., its footprint). Retailers should be honest with consumers about issues such as social impact. The advantage of the precise information needs in the use cases is that they contribute to honesty and transparency in communication with our customers. Thus, green washing can be prevented.	
Evaluation: digital product passports	The information categories in the digital product passport closely match the information needs of us as retailers. The data in the 4 detailed information categories ensure that we as retailers can provide consumers with a lot of objective information that helps them to make a well-considered purchasing decision. At the same time, as a retailer, you must avoid overloading consumers with too much detailed information. A composite number, such as the CO2 emissions or the energy class of a washing machine can be helpful. As a retailer, I should be able to click through on an item in the digital product passport if a consumer wants more detailed information.	
Evaluation: information category 1 Washing Machine Product	This information category contains all the information I need as a retailer in contact with customers who are orienting themselves towards a reusable washing machine. Warranty and remaining lifetime are important issues to communicate to customers.	Priority: Must have (primary priority, essential for lifetime extension of washing machines)
Evaluation: information category 2 Value Chain Actors	In my role as a retailer, I might need the information in this category if the customer asks for it, e.g., if the customer asks whether the washing machine is of sufficient quality. The historical information in this category might help to get an impression of the device and to answer customer questions about, for example regarding maintenance, repair history and involved actors.	Priority: Could have (desirable but not essential)
Evaluation: information category 3 Diagnostics, Maintenance and Performance	As a retailer, this category of information is very relevant to gaining more insight into the performance of the washing machines and its expected remaining lifetime. I don't need to see all the details right away, but I want to be able to make reliable statements to consumers about the technical performance of a reusable washing machine. For me as a retailer it is essential to know how long and intensively a washing machine has been used.	Priority: Must have (primary priority, essential for lifetime extension of washing machines)
Evaluation: information category 4 Sustainability and Circularity	In line with our mission, it is essential to take good care of the environment and to make our customers ecologically aware. There must be provision of clear information on any environmental damage that may occur during the product life cycle of a washing machine in the E-waste chain. As retailers, we must provide consumers with ecological information that helps them make responsible purchasing decisions in the context of a circular economy. Many large (E-commerce) retailers are not focusing on this transition in the current situation, but it will only be a matter of time before they do. This information category meets our need as a retailer to be able to provide sustainability information to customers that encourages them to make a 'green' purchasing decision. The information in the passport regarding the product design principles contributes to the principles of the 'Right to Repair' movement aiming to sell repairable washing machines that last. Consumers have the right to know how repairable a washing machine is. Information category 4 in the passport supports this.	Priority: Should have (desirable but not essential)

Feedback use case and DPP collection agents

Evaluation aspects: use cases	Feedback from respondent	
Role in use case	The collector's role transforms to return evaluation. Recognizing the residual value in a washing machine is essential here. This enables a robust response to the current collection method, in which many end-of-life washing machines are recycled. Automation and corresponding information provision are crucial to realizing the ambitions of the use case in practice. Employees at collectors must receive specific instructions on what actions they must perform. Emphasize in the use case that the collectors require a dynamic process route and information provision from their new role as return evaluation centers. The current static collection method is being replaced by a dynamic lifetime extension assessment method, in which each collected washing machine follows a unique critical path.	
Information needs	The broad information provision in the use case and the DPP enables the envisioned transition from a collector into a return evaluation center. E.g., product and product support information are lacking at present. The information needs outlined in the use case solve the problem of inadequate information provision: product, product recovery, and usage information are currently unavailable at collection points. Mention the relevance of information on parts identification and harvesting spare parts in the use case. Also mention the relationship with parts inventory systems. Washing machine discarders can provide valuable information about the condition of an appliance. This information could be registered in the DPP.	
Evaluation: digital product passports	The four detailed information categories in the digital product passport meet the information needs of a collector. The information in the passport contributes to full transparency of the chain. The information in the passport connects the chain partners in the E-waste chain. The digital product passport lacks legal guidelines regarding collecting and processing discarded consumer electronics. The success rate of the DPP is determined by the extent to which the information processes can be automated.	
Evaluation: information category 1 Washing Machine Product	Include identification data of the main parts of a washing machine in the passport. Exploded views often display identification codes. Include information on the ease with which a washing machine is repairable in this information category. A link with the indicators in the French Repair Index can be helpful in the future. The ease with which a collected washing machine can or cannot be repaired helps collectors as an assessment criterion during the grading process. Many specific features are mentioned in the "Product Features" category, such as the noise level of a washing machine. These data are less relevant for our role as graders. Consider including the list price of washing machines in the DPP. For collectors, this is an important criterion when assessing collected washing machines. Extending the lifetime of cheap washing machines is often technically and economically difficult. Chances of extending the lifetime are greater for German and high-priced washing machines.	Priority: Must have (primary priority, essential for lifetime extension of washing machines)
Evaluation: information category 2 Value Chain Actors	This category of information is helpful. Currently, collectors often guess how intensively washing machines have been used by their previous owners and to what extent maintenance and repair activities have taken place. Information on repair history is crucial for collectors but also for repairers. The repair history can be part of the assessment criteria for the lifetime extension assessment.	Priority: Should have (desirable but not essential)
Evaluation: information category 3 Diagnostics, Maintenance and Performance	Digital technologies in washing machines make it possible to carry out part of the lifetime extension assessment remotely. The detailed information categories and data closely match collectors' current and future information needs. It is essential that the current performance of washing machines also considers the device's current technical status. In this category of information, consider whether, in addition to washing machine performance, the performance of critical components is also assessed, such as the condition of the bearings or the washing machine's central control system.	Priority: Must have (primary priority, essential for lifetime extension of washing machines)
Evaluation: information category 4 Sustainability and Circularity	Ecological and social factors are becoming increasingly crucial for collectors affected by the movement towards a circular economy and changing customer behaviors. Energy and water consumption data are relevant to collectors because of rising energy prices and the importance consumers and governments attach to environmental aspects.	Priority: Could have (desirable but not essential)

Feedback commercial repairer

Evaluation aspects: use cases	Feedback from respondent	
Role in use case	On the whole, I clearly recognize myself in the use case concerning a repairman. Whether a washing machine should be repaired strongly depends on its economic value (the purchase price) and possible repair costs. Its physical condition and intensity of use also play an essential role in determining whether repair is technically feasible. Mention these considerations in the use case. Because we have access to the systems of major brands such as Bosch, AEG, and Miele, retrieving product and repair information is not a problem. In the light of the increase in digital washing machines, our repair skills are gradually changing. We have digital access with a laptop to some washing machines, such as Miele, and have access to many washing machine data. This data provides insight into diagnosis, usage, and maintenance history. Affected by the significant increase in product and usage data, our role as repairers is gradually shifting to a more information-driven one. The use case clearly outlines this digital transformation. In the use case, it is also vital for a repairer to be able to estimate possible repair costs. In line with this, it is essential to have access to spare parts databases to check whether specific washing machine parts are available. In most cases, we find specific codes and product characteristics in the databases of the major manufacturers. Mention the relevance of parts, related data, and instructions in the use case.	
Information needs	The information needs of a repairer stated in the use case are recognizable. The digitization of washing machines ensures that we have access to the data in the washing machine. As a result, we can make a diagnosis much better, see consumption, determine the device's life, and glean information on malfunctions. In reality, a diagnosis must always be physically checked by a repairer to determine the underlying causes of malfunctions. Unlike many other repairers, we have the advantage that we have access to all relevant repair information because we are certified service technicians for some brands. For non-certified brands, we have to call a support service department at the manufacturer to obtain our information. This information corresponds to the information described in the use case. It ensures that we are able to repair washing machines quickly and efficiently. As noted, it is also essential to pay attention to the washing machine's spare parts.	
Evaluation: digital product passports	The chosen format fits in well with the information we need to ensure that the entire repair process runs smoothly from our role as repairers. The digital product passport pays a great deal of attention to environmental aspects; in the future I expect that consumers will want to be better informed about the environmental aspects of a washing machine.	
Evaluation: information category 1 Washing Machine Product	OK, I found all the product information I need in this information category. We also find such information in the databases of the major washing machine manufacturers.	Priority: Must have (primary priority, essential for lifetime extension of washing machines)
Evaluation: information category 2 Value Chain Actors	This information category supports me as a repairman in finding out the process history of the washing machine. E.g., it is helpful in determining the country of origin of a device. The country where the washing machine was produced clarifies its product quality. For example, a washing machine from Germany is of a higher quality than one from Italy or Poland. I am critical of this information category because during the product life cycle, what happens to a device must be continuously registered. If this has to be done manually, it is a very time-consuming process, and the profit margin for repair will come under even more pressure. Alternatively, a washing machine would have to be connected to the internet to continuously register the various data. I think this is not realistic.	Priority: Could have (desirable but not essential)
Evaluation: information category 3 Diagnostics, Maintenance and Performance	The data in this information category are recognizable to me. The DPP should not include too many information variables in this information category (and the other parts of the passport), otherwise, the DPP will be unnecessarily complicated. The data in this information category are complete and elaborated. For us asrepairers, the usage history and the physical condition of the washing machine are the most important data to find out. I would also like to know how many wash cycles a device has run and its remaining lifetime and number of wash cycles. A good washing machine should be able to run at least 8,000 to 10,000 washes.	Priority: Must have (primary priority, essential for lifetime extension of washing machines)
Evaluation: information category 4 Sustainability and Circularity	This category of information makes the difference for a customer. The relevance of this category will only increase in the coming years. Especially with rising energy prices, we see that our customers are more actively informed in this area. We must be able to clearly indicate any energy difference and environmental benefit in order to be able to demonstrate to the customer whether it is better to repair or to purchase a new washing machine. However, this information category requires data from multiple value chain actors. Often, these data are not available.	Priority: Could have (desirable but not essential)

Feedback thrift store repairer

Evaluation aspects: use cases	Feedback from respondent	
Role in use case	I clearly recognize myself in the role of repairer in the use case. We already carry out repair work on washing machines. Decisions made during repair are based on employees' expertise and technical knowledge. However, if an employee leaves, the knowledge is also gone. The information-driven method described in the use case removes this drawback. In the current situation, the lack of brand and product-type-specific information and data on washing machines negatively impacts the number of collected washing machines that we can repair. It is sometimes difficult to find the meaning of the codes for fault diagnosis. In principle, such information can be found on websites, but more time is needed in searching for this information. The same applies when looking for repair support information & manuals. The use case indicates that historical information on a used washing machine is available. In the current situation, a producer often has such information, but it is only possible to access this information to a limited extent. I see the possibilities outlined to properly tackle our role as repairers in the use case. In addition to repair, I also foresee an essential role in maintenance to be able to extend the lifetime of washing machines. The use case rightly indicates that life-extending repair activities should be supported by information. We need assessment tools that provide information on the economic and technical feasibility and ecological benefit of any life-extending work during the diagnosis of a washing machine. At the moment, the decisions that are taken in these areas by an employee are still too subjective. The results of such tests should be documented in the digital product passport. The number of data-driven washing machines with WiFi connections has increased considerably in recent years. We will be receiving these washing machines in the near future, and in an ideal situation, we will have access to the data in those washing machines. Such a diagnosis already takes place during collection and return evaluation to objectively determine the subsequent process routes. In the process, you must carefully examine whether the diagnosis of a washing machine belongs to the use case of the 'grader', with a repairer, or whether the diagnosis takes place in broad terms at the grader and a more specific diagnosis takes place at the repairer. The last option is preferable. Another consideration is that the repair work must be able to be carried out by employees and students with a limited technical background.	
Information needs	The information outlined in the use case facilitates our testing and repair process. It is crucial for us to quickly gain insight into the most common faults in washing machines. This makes it easier to plan the repair process. I recognize the information needs I have as a repairman. Specific information, such as required tools and the degree of repairability of a washing machine, is relevant for our employees.	
Evaluation: digital product passports	In order to properly fulfill my role as a repairman, I clearly recognize myself in the four information categories. Investigate in which information categories of the digital product passport for washing machines the results of the economic & technical feasibility of any repair are registered. The ecological consequences of any lifetime extension can be recorded in information category 4: Sustainability & Circularity. The use case should indicate whether regulations have been met. The Weeelabex certification is essential to us.	
Evaluation: information category 1 Washing Machine Product	I see information category 1 as the foundation for this use case. Life-extending process activities are not possible without product-specific information. In this use case, in addition to information on product identification, the product supporting information is very important for us as repairers. This contributes to an acceleration of the repair process. In future, the software version used in a washing machine should also be included in the passport.	Priority: Must have (primary priority, essential for lifetime extension of washing machines)
Evaluation: information category 2 Value Chain Actors	This information category is beneficial when diagnosing because the washing machine's logbook provides information on its maintenance and usage history. This information, combined with information category 3 (Diagnosis, Maintenance, and Performance), helps us diagnose a washing machine's problems more quickly and determine the next steps. The information provided in this category tackles the current barrier of not having insight into the history of a collected washing machine. Based on primarily subjective visual checks and employees' experience, decisions that are difficult to substantiate are made objectively.	Priority: Should have (desirable but not essential)
Evaluation: information category 3 Diagnostics, Maintenance and Performance	This information in the digital product passport for washing machines ties in well with our information needs as repairers. It is helpful that data also include a washing machine's expected life. In the current situation, this is a 'black box.' Consider whether, in the sub-information category “Failure Diagnostics,” the main parts of a washing machine are separately included in the passport. The manual test results of the technical tests for non-data-driven washing	Priority: Must have (primary priority, essential for lifetime extension of washing machines)

	machines, such as the bearing test, could also be recorded in the passport to substantiate better decisions on possible lifetime extension. Another consideration is that a washing machine's settings are also recorded in this category of information in the passport. However, this might be too detailed. In this information category, also consider that consumers will also carry out checks themselves in the future to determine the condition of their washing machine. Facilitate this by making certain information in the digital product also accessible to this target group. To support employees with a limited technical background, add information video clips about specific process activities related to the digital product passport. This information contributes to the efficiency of our repair process. This information would correspond to information category 3.	
Evaluation: information category 4 Sustainability and Circularity	For a repairer, this information category is not primarily necessary. The data about product design can be relevant for a repairer to be able to better understand how a washing machine is constructed and which design principles were pre-eminent. For example, if many standardized connections and parts are used in a washing machine, this has a favorable effect on the repairability of an appliance.	Priority: Could have (desirable but not essential)

H. Evaluation lifetime extension assessment component version 1

Naam organisatie	EEE collection agents
Kernachtiviteiten organisatie	Inzameling en reparatie van ingezamelde wasmachines
Naam validator	Respondent geanonimiseerd
Functie	Operationeel manager inzameling en reparatie
Datum validatie	12 december 2022
1. Vandaag heb je meerdere keren gewerkt met de grading assessment tool. Alles overziend, wat zijn je ervaringen? Wat vond je goed werken? Wat niet? Welke verbeterpunten zie?	Ik vind de assessment tool voor mijzelf ook leerzaam. Ik word mij bewust van hoe ik een wasmachine beoordeel door beoordelingspunten op te schrijven. Je bent daardoor wel wat alerter denk ik. Ik vind het wel leerzaam zo'n dag. Je ziet ook meer, waar je normaal gesproken overheen kijkt.
2. Wat zijn volgens u kritieke factoren die relevant zijn bij het beoordelen van een afgedankte wasmachine op een inzamelpunt om te bepalen of deze mogelijkerwijs in aanmerking komt voor levensduurverlenging?	Er valt niet veel op de tool aan te merken, het is een assessment in de beginfase. Ik denk dat de assessment tool wel zou werken bij onze inzamellocatie en ons ook zou helpen. Zeker als je hier als leek binnenkomt, dan geeft de tool wel verduidelijking. Iemand die hier binnenkomt, die komt door de assessment tool wel een heel stuk verder. Omdat wij er al langer werken, is de assessment tool niet direct nodig. Wij zien een wasmachine en weten direct of deze wel of niet in aanmerking komt voor levensduurverlenging. Ik denk dat iemand die hier op de inzamellocatie begint, dat je daar eens een test met de assessment tool zou moeten gaan afnemen.
3. Welke factoren zou u willen toevoegen aan het prototype van de grading assessment tool? Wat is hierbij uw argumentatie?	Ik denk dat het inzamellocatie beïnvloedt welke factoren onderdeel moeten uitmaken van de assessment tool. Wij zijn bijvoorbeeld heel erg merkgericht door alleen Duitse merken te selecteren voor reparatie. De assessment kan al heel kort zijn dat als een wasmachine geen Duits merk is, dan is het voor ons al klaar en is verdere assessment niet nodig. Voor ons zou de tool korter kunnen, maar je weet niet wat de toekomst gaat brengen, bijv. dat meer gerepareerd gaat worden. Ik denk dat het voor iedere inzamellocatie anders is. Je kunt nog toevoegen als assessment criterium dat wasmachines minimaal een laadgewicht van 7 kilogram moet hebben. We zien namelijk dat er geen marktvraag is naar wasmachines die maar een klein laadgewicht hebben. De manier waarop wasmachines zijn geconstrueerd door een producenten heeft een grote invloed op hun repareerbaarheid. De lage prijzen van de wasmachines wegen niet op tegen de inspectie- en reparatiekosten die je bij levensduurverlenging maakt. Het ligt bij een producent om een wasmachine anders te gaan ontwerpen. Levensduurverlenging van wasmachines die geen A-merk zijn, is economisch niet haalbaar. Dus het is correct om alleen Duitse merken wasmachines te selecteren. Ook Zanussi kun je aanmerken als een Duits merk omdat de onderdelen van Duitse origine zijn en daarom dezelfde productkwaliteit hebben. Zanussi is een dochter van AEG. Wat lastig is tijdens de assessments, is dat binnen de Duitse merken de productkwaliteit van de wasmachines sterk kan verschillen. Het land waar een wasmachine is geproduceerd, bijv. Polen of Spanje, beïnvloedt in sterke mate de levensduur van een wasmachine. Je kunt het productieland afleiden uit de relatief kleine deur, het klepje naar de pompfilter en de lage materiaalkwaliteit. Je zou in je tool eventueel kunnen meenemen dat je een check op het productlabel doet of daar staat genoteerd "Made in Germany". Maar in de praktijk is dit lastig omdat deze niet altijd is genoteerd op het product label. Je moet het dan toch afleiden uit uiterlijke kenmerken van de wasmachines. Dit vraagt impliciete productkennis van de leek bij het beoordelen van wasmachines die zich lastig in een assessment tool laat vastleggen. Kortom, het is een relevant assessment criterium, maar de resultaten van een lagertest zijn erg belangrijk om te bepalen of levensduurverlenging mogelijk is. Als de lagers al kapot zijn, dan is verder onderzoek aan de wasmachine niet meer nodig, dan is het klaar. We zien in de praktijk dat bij veel wasmachines onderdelen ontbreken, zoals klepjes, control panels en deuren. Dit is vaak voor derde partijen een lucratieve handel. Wij oogsten veel onderdelen en kunnen dit makkelijk herstellen, maar als je geen onderdelen oogst dan is het economisch moeilijk haalbaar om ontbrekende onderdelen te vervangen.
4. Welke factoren in het prototype van de grading assessment tool zou u willen verwijderen? Wat is hierbij uw argumentatie?	Je maakt tijdens de assessment veel foto's van de wasmachine. Dit kost tijd. Je kunt al heel goed aan de voorkant van een wasmachine zien hoe de fysieke staat van een apparaat is. Een foto zou dan volstaan. Ook de leeftijd van een wasmachine is lastig te bepalen. Op de wasmachines van AEG, Bosch en Siemens staat de leeftijd indirect op het productlabel. Voor de andere merken kan het bouwjaar niet worden achterhaald vanaf een productlabel. Dit is wellicht mogelijk via het internet of door in te loggen op de websites van de wasmachine producenten. Echter, de inloggegevens hebben wij niet. We merken ook dat het voor onze laaggeschoolde medewerkers te moeilijk is om hen uit te leggen hoe een productlabel op een wasmachine geïnterpreteerd moet worden. Dit zijn voor ons de overwegingen om leeftijd niet op te nemen in de check op levensduurverlenging. We kijken vooral naar de visuele staat van Duitse wasmachines.

	De wasmachines komen met trucks bij ons binnen op de inzamellocatie. Wij kunnen niet achterhalen wie een wasmachines heeft afgedankt. Daarom is het niet mogelijk om de vraag te stellen of een wasmachine functioneert.
4. Als u uw antwoorden op vraag 2, 3 en 4 bekijkt, wat zijn volgens u de kritieke grading assessment factoren die volgens u onderdeel dienen uit te maken van een grading assessment factoren?	Alle belangrijke beoordelingsfactoren maken onderdeel uit van de tool: Duits merk, lagertest en visuele inspectie.
5. In hoeverre is het is volgens u gewenst om de grading assessment factoren wel/niet volgordelijk uit te voeren? Wat zijn hierbij uw overwegingen?	Wij kijken of een wasmachine een Duits merk is en of de lagertest acceptabel is. Als hier geen sprake van is, dan is het snel einde oefening.
6. Wat zijn volgens u passsende antwoordcategorieën bij elke grading assessment factor? Wat zijn hierbij uw overwegingen?	De antwoordcategorieën zijn prima. Eventueel kunnen de 3 antwoordcategorieën nog tot 2 antwoordcategorieën worden samengevoegd om het scoren te vereenvoudigen voor een assessor.
7. Heeft u verder nog opmerkingen die belangrijk zijn bij het ontwerpen van de grading assessment tool?	Als je apart onderdelen moet bestellen dan is het hek van de dam. Dat is financieel gezien niet te doen. De economische haalbaarheid van reparatie wordt sterk beïnvloed door de kosten van de onderdelen. Doordat wij onderdelen oogsten uit bestaande wasmachine kan reparatie economisch haalbaar zijn. De lage loonkosten van medewerkers met een afstand tot de arbeidsmarkt zorgen er ook voor dat eventuele reparatie economisch nog haalbaar kan zijn. We zouden de levensduur van nog veel meer wasmachines kunnen verlengen. Er zit heel veel potentie. De assessment tool kan hierbij helpen.

I. Observations and lessons learned during validation of lifetime extension assessment component version 2

Consideration		Consequences for assessment component
1.	It is unclear to which assessment criterion damage around the control panel relates (scratches, minor dents).	State in the acceptance standard that a control panel must be damage-free.
2.	The layperson faced difficulties with locating the product labels for some washing machines.	No consequences for the assessment component. Include as a point of attention in micro training.
3.	The expert rejects a washing machine because the control panel has yellowed.	The expert rejects a washing machine because the control panel has yellowed. A yellowed control panel is considered acceptable.
4.	The established acceptance standard for the year of construction was set at ten years. The expert estimated the chance of extending service life mainly based on the bearing test, whether or not it was a German brand, and the visual condition of the washing machine. Because parts are harvested, and German washing machines are repaired, age is a less relevant criterion.	Before carrying out assessments, it is essential to make explicit the basic principles and preconditions for extending lifetime. Before assessments take place, enter into the settings of the assessment component whether parts are harvested and collected, and washing machines are repaired. Maintain the year of construction assessment criterion for the time being.
5.	Over half of the washing machines have missing parts, such as electronics, doors, door suspension, and soap dishes. Power cables and hoses are frequently cut. For an expert, contrary to the strict acceptance standards of the lifetime extension assessment component, the lack of parts is not a reason to reject a washing machine because the organization has many parts in stock.	Specify whether a collection location harvests parts to estimate whether any repair is economically feasible. A missing power cable is acceptable as it can be safely repaired. This assessment criterion is therefore removed from the assessment component.
6.	The frequency of missing washing machine power cables means that a quick test cannot be carried out to determine whether they are still receiving power.	Remove assessment criteria about the functioning of the washing machine.
7.	Certain parts of washing machines, like soap dishes, are dirty and not hygienic. Observations in the repair workshop at the collection location make it clear that cleaning is possible.	No consequences for assessment criteria. Include a cleaning process activity as part of the repair process.
8.	The expert regularly checks a washing machine for traces of repair. Unprofessional repair harms the life of a washing machine.	Relevant assessment criterion, but difficult to standardize in an assessment component due to the multitude of possible repairs and related repair traces.
9.	The expert often knows whether a washing machine is suitable for lifetime extension or not. If a specific assessment criterion is not acceptable, further assessment is useless.	Include strict 'if…then' conditions in the final version of the lifetime extension assessment component. If an acceptance standard is not met, the assessment stops. Test all assessment criteria in the next version.
10.	In addition to having a preference for German washing machine brands, the expert selects by product type. There is a specific market demand for certain product types.	Maintain a selection of German washing machine brands. The number of product types is so large that clear selection is complex.
11.	The expert selects washing machines that may or may not function but are promising for refurbishment on specific parts, such as shock absorbers and carbon brushes.	Before performing assessments in settings, it is essential to enter data on whether parts are harvested and collected washing machines are repaired or overhauled.
12.	According to the expert, the country of production of a washing machine provides information about product quality.	No primary assessment criterion and information about the specific country of production is difficult for a layperson to determine.
13.	The layperson was able to perform the bearing test properly. 37 of the 41 bearing tests were performed well when compared with the expert. In some bearing tests, the layperson was confused about whether the bearings or the shock absorbers had failed.	Maintain bearing test acceptance as an assessment criterion. In micro preparatory training, laypersons are trained to perform a bearing test.
14.	The characteristics of properly functioning bearings, depending on the motor type, can differ per brand and product type.	Instructing laymen during micro-training sessions on how to perform a bearing test and how to interpret the test results.
15.	During the visual checks of some washing machines (<5), the layperson missed rust spots, dents, and missing parts, whereas the expert did observe these.	Experience in working with the assessment component and micro-training that the layperson should pay attention to during the visual checks contribute to an accurate assessment.
16.	The layperson experienced uncertainty when estimating the age of the washing machines. Age estimation was impossible for the brands Miele, Zanussi, Samsung, LG, Indesit, and Whirlpool.	Notches on the side of the washing machine indicate its relative age, whether it is 'older' or 'younger.'

17.	The collector cannot indicate washing machines equipped with digital technologies. The manufacturer does not grant access to this information. This is a risk for collection because the number of digital washing machines will increase sharply in the coming years.	Maintain pragmatic assessment criteria in the component in the short term to reduce dependency relationships between collectors and producers. Any future lifetime extension assessment component should be data-driven by design.
18.	A washing machine's completeness and visual condition are essential assessment criteria for the expert.	Maintain visual checks for completeness and visual condition.
19.	The expert rejects washing machines with a load weight of less than 7 kilograms due to limited market demand.	Observations clarify that most washing machines have a load weight of 7 kilograms or more. A smaller loading weight is an exception. Do not add a separate assessment criterion on load weight.
20.	Excessive rust near the soap dish and the underside of a washing machine indicates a leak. Peeling paint is an indication of rust.	No consequences for the assessment component. During micro-training courses, laypersons are trained to detect rust spots.
21.	The expert checks a washing machine for incoming and outgoing hoses and aqua stop.	No consequences for the assessment component. Missing hoses are relatively easy to repair.
22.	The expert selects German brands because there is a greater market demand for them in thrift stores.	Maintain washing machine brand assessment criterion.
23.	Some washing machines had cracks on the top plate. Such cracks do not influence the technical functioning of the washing machine and therefore do not lead to the rejection of a washing machine.	Cracks are not a separate assessment criterion in the assessment component.
24.	The expert often mentions that a washing machine looks good or bad. This confirms that visual checks for rust, dents, and completeness are essential to the assessment component.	Maintain visual checks in the assessment component.
25.	The inside of a cuff can contain mold. Smell is an indicator. Mold can indicate leaks.	Not relevant as an assessment criterion..
26.	The layperson found that, with some washing machines, its door could not be opened.	Leaks in a micro training session instructing alternative ways to open a washing machine door.
27.	During the assessment, it was unclear under which criterion an improperly closing and incomplete door falls.	Maintain assessment criteria. Instruct laymen in micro-training sessions on which specific bottlenecks are part of which assessment criterion.
28.	The expert indicated that sometimes washer-dryer combinations also come in. Due to their limited repairability, they are not eligible for service lifetime extension.	Washer and dryer combinations are not eligible for lifetime extension.

J. Evaluation lifetime extension asessement component version 2

Naam organisatie	Foenix
Kernachtiviteiten organisatie	Inzameling en reparatie van ingezamelde wasmachines
Naam validator	Kees van Grimmelikhuisen
Functie	Operationeel manager inzameling en reparatie
Datum validatie	28 december 2022
1. Vandaag heb je meerdere keren gewerkt met de grading assessment tool. Alles overziend, wat zijn je ervaringen ? Wat vond je goed werken? Wat niet? Welke verbeterpunten zie?	- Het viel mij tijdens de assessment van de ingezamelde wasmachines op dat er veel Duitse merken wasmachines waren. De niet-Duitse merken vallen af voor levensduurverlenging als je de acceptatienormen t.a.v. Duits merk streng hanteert. Omdat we de product-en gebruiksdata niet hebt van bijv. de Samsung wasmachines zou je deze apparaten eigenlijk willen doorsturen naar de werkplaats om te waarom deze wasmachines door een vorige eigenaar zijn afgedankt. We hebben geen inzicht in de oorzaken waarom wasmachines van dit merk, maar ook van andere merken, kapot zijn en in hoeverre het mogelijk is om de levensduur te verlengen. We hebben een informatietekort. Dit maakt het moeilijk om onderbouwde uitspraken over levensduurverlenging van wasmachines te kunnen doen. - Het werken met de assessment tool vond ik goed te doen. Je komt heel duidelijk tot een oordeel of levensduurverlenging haalbaar is of niet. Het is alleen lastig om voor enkele merken wasmachines de leeftijd te achterhalen. In de assessment tool wordt op verschillende manieren gevraagd naar de leeftijd van een wasmachine, maar doordat informatie niet beschikbaar is, kan ik deze vragen over leeftijd niet beantwoorden. - Het eindoordeel van de assessment tool of levensduurverlenging mogelijk vond ik juist. Los van de assessment tool was ik ook tot hetzelfde oordeel gekomen. Iemand anders die geen verstand heeft van wasmachines die zal die tool echt wel nodig hebben. De assessment tool expliciteert de beoordeling die ik als expert zelf ook zou doen. Ik vind het een een prima assessment tool die op onze inzamellocatie ingezet zou kunnen worden. De assessment vragen die in de tool zouden moetem zitten, maken onderdeel uit van de tool. Je zou natuurlijk nog veel verder kunnen nadenken. Bij wasmachines zoals Samsung zou je het eindoordeel nog verder kunnen onderverdelen, bijv. acceptabel, twijfelachtig of niet-acceptabel. Dit zou nog ruimte kunnen bieden voor een reparateur om zelf te beoordelen of levensduurverlenging mogelijk is of niet. - De tijd die het kost om een assessment uit te voeren vond ik snel gaan. Geen commentaar. De simpele opzet van de lifetime extension assessment tool spreekt aan. Ik denk dat de assessment tool hierdoor in de praktijk kan worden geïmplementeerd om je heel snel op basis van eenvoudige vragen een duidelijk antwoord krijgt of levensduurverlenging haalbaar is. Op een inzamellocatie is het vooral belangrijk dat de assessment tool simpel is.
2. Wat zijn volgens u kritieke factoren die relevant zijn bij het beoordelen van een afgedankte wasmachine op een inzamelpunt om te bepalen of deze mogelijkerwijs in aanmerking komt voor levensduurverlenging?	- De factoren die onderdeel moeten zijn bij de beoordeling van een wasmachine zijn opgenomen in de assessment tool. Wat mij opviel is dat je goed naar deuken in de constructie van de wasmachine moet kijken. Je zou eventueel nog kunnen overwegen om de trommelgrootte van de wasmachine als assessment criterium op te nemen, maar dit is vooral bij oudere wasmachines. Bij nieuwere wasmachines zijn de trommels groter. - Wat je met de assessment tool er niet uit haalt is of de wasmachine een energieslurper is of niet. - Leeftijd vind ik een lastig beoordelingscriterium omdat je bij veel merken wasmachines gewoon niet hoe oud deze zijn. We hadden een tijd terug de acceptatienorm gesteld op 10 jaar, maar dat kan best ruimer. Maar het probleem blijft dat het voor veel apparaten niet duidelijk is hoe oud deze zijn. De assessment wordt te complex als je databanken in zou moeten om de leeftijd van wasmachines te achterhalen. De beoordeling op levensduurverlenging hangt dan echt af van het uiterlijk van de wasmachine, de compleetheid en de resultaten van de lagertest. Dit is namelijk wat je kan doen bij het assessment. Deze factoren zijn verwerkt in de assessment tool. - De visuele checks op de compleetheid van een wasmachine moeten gehandhaafd blijven. Een ontbrekend klepje naar de pompfilter is acceptabel want daar kan je als reparateur op in spelen. Om een wasmachine af te keuren op een ontbrekend klepje vind ik geen optie. Zeker als je onderdelen gaat oogsten en in dit geval klepjes naar het pompfilter worden geoogst uit wasmachines die niet in aanmerking komen voor levensduurverlenging. - De keuze voor twee antwoordcategorieën is acceptabel. Een eventuele derde tussencategorie vraagt veel kennis van een assessor, deze kennis is er vaak niet. De keuze voor de huidige twee antwoordcategorieën in de assessment tool is daarom beter.
3. Welke factoren zou u willen toevoegen aan het prototype van de grading assessment tool? Wat is hierbij uw argumentatie?	Zie boven. Ik zou geen factoren willen toevoegen aan de assessment tool. De eenvoud en simpelheid van de assessment tool maken de tool juist bruikbaar voor onze inzamellocatie. De beperkte opleidingsachtergrond van onze medewerkers vraagt om een eenvoudige tool.
4. Welke factoren in het prototype van de grading assessment tool zou u willen verwijderen? Wat is hierbij uw argumentatie?	Je zou kunnen overwegen om de assessment criteria over deur en deurophanging te combineren, maar dit is zeker geen harde eis. Ik begrijp dat het nu afzonderlijke criteria zijn omdat de check op deurophanging nogal specifiek is.
5. Als u uw antwoorden op vraag 2, 3 en 4 bekijkt, wat zijn volgens u de	De foto's die zijn genomen van de wasmachine zou ik voorlopig handhaven omdat het veel informatie geeft over de staat van een wasmachine. We gaan steeds meer toe naar een datagedreven

kritieke grading assessment factoren die volgens u onderdeel dienen uit te maken van een grading assessment factoren?	assessment van wasmachines. Tegelijkertijd kost het nemen van de foto's tijd. De visuele checks zouden idealiter ook vanaf een foto kunnen worden bepaald.
6. In hoeverre is het is volgens u gewenst om de grading assessment factoren wel/niet volgordelijk uit te voeren? Wat zijn hierbij uw overwegingen?	Het eerste deel van de assessment waarin wordt gevraagd naar voorlader, merk en lagertest moet je in deze volgorde handhaven. Het is een duidelijke ja of een duidelijke nee. Stop het assessment direct als op een van de factoren 'nee' wordt geantwoord.
7. Wat zijn volgens u passende antwoordcategorieën bij elke grading assessment factor? Wat zijn hierbij uw overwegingen?	Je zou bij de visuele checks eventueel met een multicriteria-analyse kunnen werken, maar tegelijkertijd spreken de twee antwoordcategorieën in de assessment tool aan omdat je alle niet acceptabele roest, deuken en ontbrekende onderdelen er direct uit selecteert. Houd voor nu de twee antwoordcategorieën aan. Bij eventuele twijfel zou je een wasmachine moeten doorsturen voor aanvullend onderzoek. Ondanks de assessment tool is er altijd een stukje technische kennis van een medewerker nodig om specifieke gevallen te beoordelen, zoals de ernst van een roestplek.
8. Heeft u verder nog opmerkingen die belangrijk zijn bij het ontwerpen van de grading assessment tool?	In deze fase van de ontwikkeling van de assessment heb je logischerwijze nog te weinig data hoeveel wasmachines daadwerkelijk voldoen aan de assessment criteria om voor levensduurverlenging in aanmerking te komen. Dit kan pas in een volgende fase worden bepaald als met de assessment tool op de inzamellocatie wordt gewerkt, duidelijk wordt hoeveel ingezamelde wasmachines in aanmerking komen voor levensduurverlenging en wat veelvoorkomende assessment criteria zijn die leiden tot het afkeuren van een wasmachine. We hebben meer data nodig om v oor meer wasmachine merken te weten weet wat veelvoorkomende problemen zijn. Als we deze data hebben en de inzichten die daaruit volgen, dan kan je merken gaan toevoegen. De kennis die daarmee opdoen helpt om specifieker op merk en producttype wasmachines te beoordelen. Bijv. dat je weet dat bij een bepaald product type het bedieningspaneel vaak kapot gaat of de schokdempers het snel begeven. In je assessment kan je daar dan rekening mee houden.